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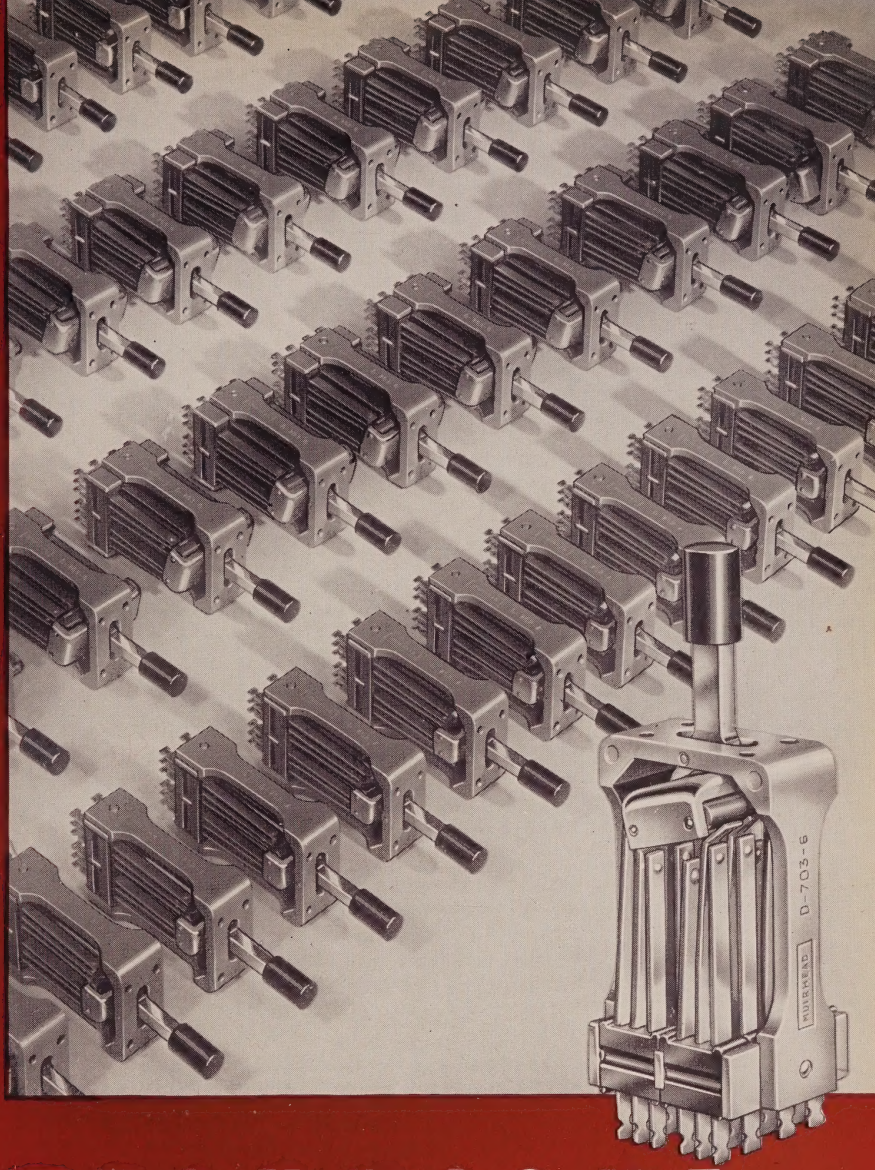

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THE FRONT COVER

Miniature Key Switches, the subject of our cover design, are a recent addition to our range of high quality components. They are a smaller version of our well-known Low Capacitance Key Switches and were first developed for inclusion in our own instruments where space considerations precluded the use of the larger type.
Over a period of years they have proved eminently reliable and we are confident that they will give equal satisfaction wherever Key Switches are required.
Publication 6732-A, giving full details, may be had on request.

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Following the announcement in the April issue, 1955, we are pleased to add that our production of Synchros made to U.S. Bureau of Ordnance Specifications has been increased to include the following types:—

Size 18 18CX4a Control transmitter 18CDX4a Control differential transmitter
18CT4a Control transformer MK 8 MOD 0 Servo Motor

Size 15 15CX4a Control transmitter 15CDX4a Control differential transmitter
15CT4a Control transformer

Size 11 11CX4a Control transmitter 11 CT4a Control transformer

All of the above elements are suitable for operation from a 115v 400c/s supply.
Data sheets giving full technical information on these synchros are available on request.

PHYSICAL SOCIETY EXHIBITION 1956

The 40th Physical Society Exhibition will take place from Monday 14th May to Thursday 17th May 1956 inclusive in the Royal Horticultural Society's two Halls, Grey Coat Street, Westminster, S.W.1. As usual a discourse or demonstration lecture will be given on each evening of the Exhibition. We shall be exhibiting on Stand No. 73, and the following instruments will be shown:

A range of Synchros, D-696 Hydraulic Relay, D-768 Gyro Controlled Hydraulic Unit, D-774 Resolver No. 2 Amplifier, D-695 Decade Oscillator, D-728 Impedance Angle Meter, D-729 Phase Meter, D-746 Impedance Converter, D-783 Square Wave Shaper, D-788 Low-Frequency Analyser and D-770 Portable Picture Transmitter.

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APPLICATION OF MAGSLIPS IN A WAVE-GENERATOR

By Hjalmar Christensen M.A.

Senior Scientific Officer of the Skipsmodelltanken (The Norwegian Ship Model Experimental Tank)

THE use of a model test tank for the determination of the optimum hull shape of a ship and its propellers has in the past mainly been confined to smooth water conditions. In the recent years, however, there is a general tendency to extend the tests, at least in some cases, to include more realistic ones in simulated rough sea conditions. The reason for this is that an optimum smooth water design is not necessarily an optimum rough sea design, and the latter may frequently be the more desirable solution.

To simulate rough seas in an ordinary test tank the latter has to be provided with a wave generator or wave-maker at one end and a wave absorbing beach at the other end. We shall limit ourselves to discussing the wave-generator only, and particularly the specimen built at the Skipsmodelltanken in Norway.

THE WAVE-GENERATOR AT THE SKIPSMODELLTANKEN

For systematic work it is necessary to be able to generate regular waves within specified length (frequency) and amplitude ranges. In the case of the main test tank of the Skipsmodelltanken, 567 feet long, 35 feet wide, 18 feet deep, this range has been tentatively specified as 7–40 feet for the wave-length and 4–18 inches for the corresponding maximum wave-height.

The wave generating element of the machine (Fig. 1), is a beam of elongated cross-section A which is suspended across the tank near the end wall under the surface of the water at a certain fixed depth *d*. This beam can be given a harmonic translatory motion in the horizontal plane by means of a lever system *l-l*, driven, through an eccentricity device in the form of a variable throw crank *e*, by a 40 H.P. D.C.-motor. The frequency of the beam oscillations can be varied between 0·05 and 1 c/s. The frequency is the parameter which determines the wave-length λ. The amplitude of the beam motion is governed by the setting of the crank *e* and is the wave-height *h* determining parameter at a given wave-length. As the beam is oscillated under the surface of the water the waves

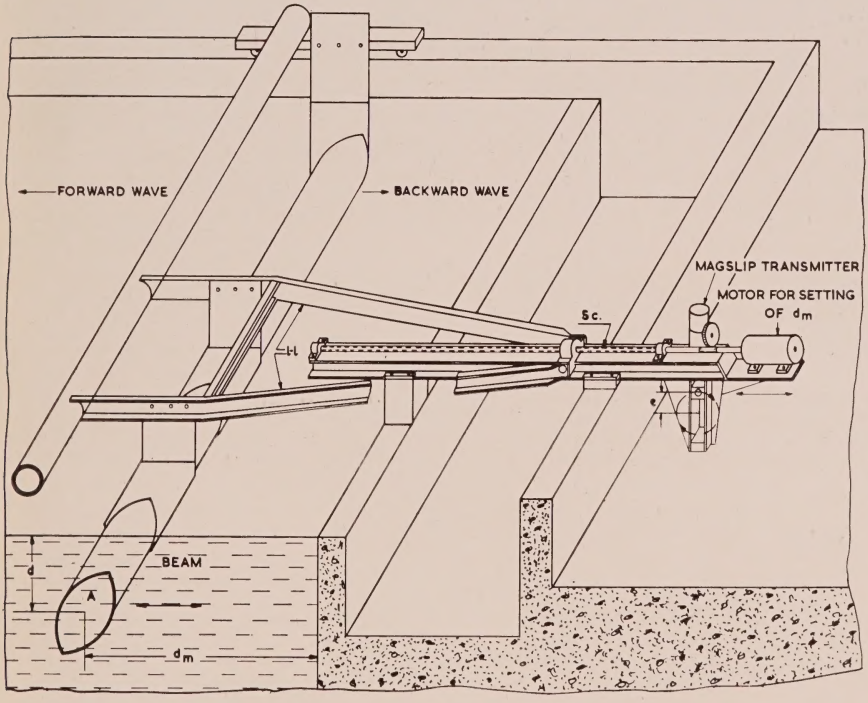


Fig. 1. Diagram showing beam and oscillatory and positional controls

are built up on the surface, and travel in both forward and backward directions. The backward wave hits the end wall of the tank and is reflected forwards. The distance d_m from the middle position of the beam to the wall has to be adjusted for each wave-length to give proper phase relationships between the forward and the reflected waves. The optimum setting of the distance d_m is around the value of $0{\cdot}4\ \lambda$ and is best set by observing the load on the driving motor, this being a minimum at the correct adjustment of the distance d_m. This adjustment problem seems somewhat akin to the problem of matching a radio-frequency oscillator to a line or a wave-guide, hence we term the distance d_m the matching distance.

APPLICATIONS OF MAGSLIPS IN THE WAVE-GENERATOR— REMOTE INDICATION

The screw Sc driven by an induction motor adjusts the distance d_m. To the same screw a Muirhead Magslip Transmitter is coupled through suitable gearing. The corresponding Magslip Receiver is placed on the wave-generator control desk (Fig. 2) above the motor control buttons. The scale of the receiver is graduated directly in the appropriate d_m values in metres. Similarly the throw of the crank and hence the eccentricity is adjusted by a D.C.-motor to which a Magslip Transmitter is coupled the corresponding Magslip Receiver also being mounted on the control desk. Since during the wave generating process the stators of the control motor and the Magslip Transmitter are revolving at the drive shaft speed, the connexions to these are brought out through sliprings and brushes; this can be seen in Fig. 3. The Magslip Receiver for the eccentric control is graduated directly in millimetres of eccentricity.

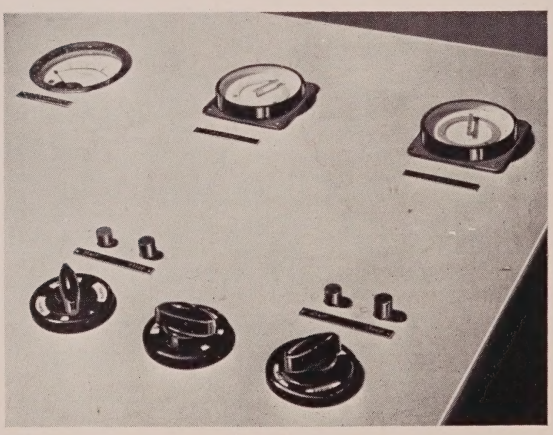


Fig. 2. Control desk showing Magslip receivers

The use of Magslips as described above greatly simplifies and speeds up the setting of the parameters d_m and e, and is in our case directly labour saving. We have placed the control desk for the wave-generator beside the control desk for the towing carriage for the models, both located in a control room situated at the opposite end of the tank.

The control of the wave-generator is sufficiently simple for one man to handle both it and the towing carriage.

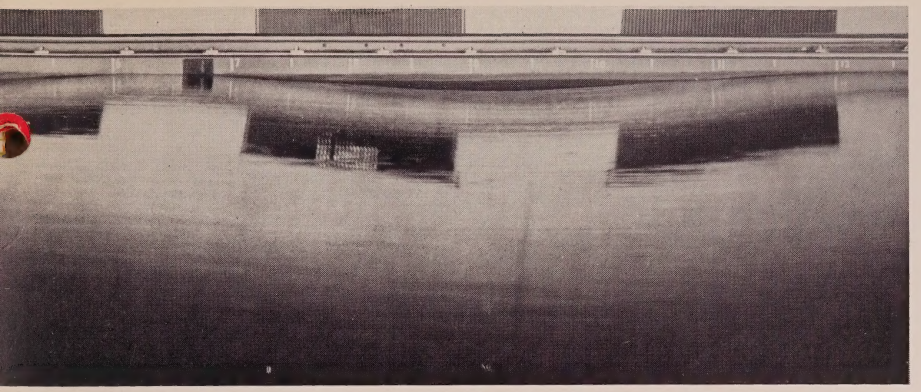
THE DRIVE FOR THE WAVE-GENERATOR

A few words might be of interest in connexion with the drive for the wave-generator. The drive consists of a 40 H.P. D.C.-motor driven from a feedback controlled Ward-Leonard set. The feed-back system incorporates a tacho-meter generator coupled to the motor and a 1·6 kW amplidyne to control the field of the main generator of 33·5 kW. The reference voltage potentiometer for the speed selection is equipped with a Muirhead Dial and Drive which enables us to select the desired speed quickly and exactly. We have equipped the dial with a small handle so as to be able to turn it faster, and an anti-backlash 2 : 1 gear is driven by the output to enable the 180° dial to operate our 360° potentiometer.

We consider that feedback control has certain advantages in our case: wide speed range, less dependence of speed on mains voltage and frequency fluctuations, greater speed constancy for the cyclically varying load which the wave-generator represents and fast run up possibilities.

CONCLUSIONS

The wave-generator is still under the test and we cannot yet give the final figures as to the hydrodynamic efficiency, wave-shapes and sizes and so on. We have, however, completed the adjustments and checks on the auxiliary machinery, including the Magslips, which works up to the specifications.



Typical wave produced by the wave-generator. Frequency of oscillation of beam 20/min; wavelength 6 m; wave height 16 cm.

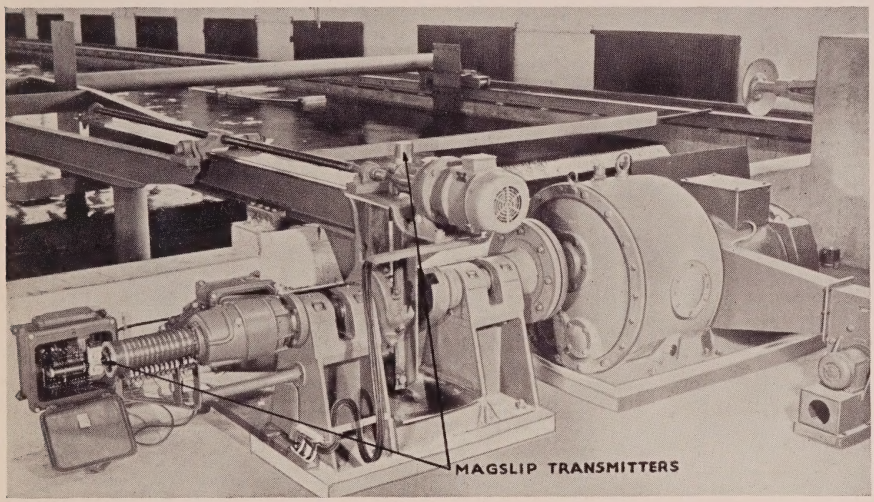


Fig. 3. Wave-generator drive mechanism

MUIRHEAD COMPONENTS EMPLOYED IN THE WAVE-GENERATOR

	Type No.
2-inch Magslip transmitter for matching distance control	E-1-A/1
Magslip Indicator for matching distance control	D-505
2-inch Magslip transmitter for eccentricity control	E-1-A/1
Magslip Indicator for eccentricity control	D-505
Dial and Drive for reference voltage potentiometer	D-206-A

ACKNOWLEDGMENTS

The design of the electrical system for the wave-generator is due to the author, who also has carried out the initial tests of the wave-generator. The mechanical design is mainly due to Scientific Officer A. Vatne. Many people have been engaged in the designing and building of the wave-generator, the principal participants being: E. Brensholm, S. Lyng, I. Marken, F. Selliseth and T. Stigum.

MUIRHEAD INSTRUMENTATION IN THE BIRMINGHAM PROTON SYNCHROTRON

By L. U. Hibbard B.Sc. M.E. Ph.D.*

In a synchrotron particles are constrained by a magnetic field to remain on a fixed circular orbit and are accelerated by the application of an electrical impulse in each revolution. In order to determine the frequency of application of the electrical impluses as an accurate function of a rising magnetic field Messrs Muirhead and Co. collaborated with the Birmingham University's Physics Department in developing a 0·25 to 10 Mc/s beat-frequency oscillator which was tuned by a large rotating condenser driven by a velocity-controlled servo system. For the latter a standard type A–816–C phonic motor was adapted so as to provide a rapidly controllable source of torque.

PROTON SYNCHROTRON

THE Birmingham University's synchrotron was designed to accelerate protons from an energy of some hundreds of kilovolts up to a maximum of 1 000 million volts. The protons are injected tangentially into a toroidal vacuum box and are held within the cross-section of the box for one second by means of a vertical magnetic field. During this 'interval' each proton describes 5 000 000 circuits of the toroid, each time receiving an increment of 200 electron volts in energy in passing through a metallic 'drift' tube excited to a radio-frequency potential of 240 volts r.m.s.

As the energy increases the momentum and frequency of revolution increase, necessitating a progressive rise in the constraining magnetic field and in the frequency of the accelerating radio-frequency potential. The former is achieved by connecting a 1 100 volt D.C. generator across the magnet winding and allowing a current to build up to 12 000 amps in a second. The latter is achieved by means of a wide-band power amplifier controlled by a beat-freqency oscillator which sweeps from 0·25 to 10 Mc/s in the same time. The required relationship between frequency, f, and magnetic field, B (Kilogauss), is

$$f = \frac{10{\cdot}603\ B}{\sqrt{B^2 + 48{\cdot}380}}\ \text{Mc/s}$$

with an accuracy varying from 0·1 per cent for low values of f to 1 per cent for the higher values.

The constraining magnetic field would be an accurately repeating function of time if it were possible to stabilize the generator voltage. This is too difficult to do because the accelerating period recurs with a 10-second cycle and there is barely time for the rotating machinery to get back to its required speed between one pulse and the next. Thus, it is not sufficient to generate the accelerating radio-frequency as a function of time only, but it is necessary to relate it more directly to the magnetic field or to the generator voltage. The latter was chosen as a reference since it gives valuable advance information of the magnet law to be expected at the start of each cycle, where the highest frequency accuracy is required.

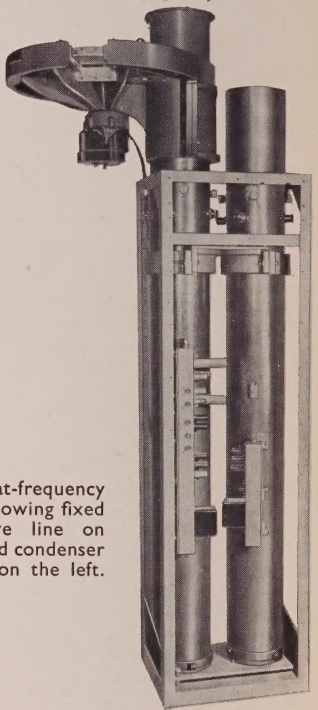


Fig. 1. Beat-frequency oscillator showing fixed quarter-wave line on the right and condenser tuned line on the left.

BEAT-FREQUENCY OSCILLATOR

The beat-frequency oscillator comprises a fixed oscillator (33 Mc/s) and a variable oscillator (33 to 23 Mc/s), both of which consist of quarter-wave coaxial lines of about 7 ft. in length, as shown in Fig. 1, with coupling loops coming out to the oscillator valves mounted on the outer tubes. The variable oscillator has a two-vane stator mounted on the top end of its inner tube and a large single-vane rotor meshing with it. The rotor is driven by a phonic motor through a 12 to 1 helical reduction gear, and accurate relation of the beat frequency to the magnetic field is ensured by control of the phonic motor input and by initiating the magnet cycle with a trigger derived by optical means from the condenser rotor.

*Now at the Australian National University

SERVO SYSTEM FOR CONDENSER CONTROL

The basic object of the servo system is to ensure that the condenser speed is proportional to the generator voltage at the instant when the latter is applied to the magnet. After the first 10 msec or so the accuracy of speed control can be allowed to fall off and, in fact, there is no real need to make the speed follow further changes in the magnet voltage. The generator voltage controls are adjusted so that, in general, the nominal value of 1 100 is approached half a second or so before the start of the cycle. A reference voltage supply of 1 100 V is inserted in series with the generator so that the control voltage applied to the servo-control unit is zero if the correct voltage is reached. As the resultant control voltage approaches within 22 V of zero it takes control of the servo, which has to follow any change thereafter. To meet all the conditions the servo was required to follow a maximum rate of 200 V per second within the prescribed limits of 1 100 ±22 V and to introduce a lag of no more than 0·1 per cent for a voltage rate of 50 V/sec.

The principle of the servo system is to measure the time taken for the condenser disc in rotating through an angle of 3°, to compare it with a reference time-interval, as modified in accordance with the control voltage, and to determine the magnitude and sign of the motor torque for the next 3°. Thus, at the same time as each speed correction is being carried out, the speed measurement which will determine what is to happen during the next 3° of rotation is also being made.

The elements of the servo system are shown in Fig. 2 in block diagram form. Light pulses reflected from sharp-edged mirrors set accurately at every 3° around the condenser disc give rise to current pulses at approximately 10 msec intervals in a photomultiplier in unit A. From this unit, output-voltage pulses are fed to the time-interval comparator C, together with pulses delayed by a nominal 10 msec from the reference-time-interval generator, B. In C, a square voltage-waveform is generated with length equal to the time interval between each delayed pulse and the immediate following mirror pulse. This is converted in D to a D.C. voltage which controls the power output of the servo-drive unit, E. Control is effected in such a way as to try to maintain the mirror-pulse interval longer than the reference interval by a constant amount of 0·1 msec. The condenser-disc speed is thus made to follow any variation in the reference interval, and the overall control of speed as a function of an applied D.C. control-voltage is achieved by suitably varying the reference interval produced by B. The basic reference intervals are initiated by each mirror pulse closing a gate which admits 1·25 μsec pulses from a crystal oscillator to a scale of 8 000 circuit. When the count of 8,000 (10 000 μsec) has been reached, the gate is switched off again automatically and waits for the next mirror pulse to open it again. The period for which the gate remains open is lengthened or shortened respectively by the suppression of a number of the input pulses to the scaler or the addition of a train of interleaved ones. This is done with the aid of gates controlled by square waveforms derived from the input control voltages.

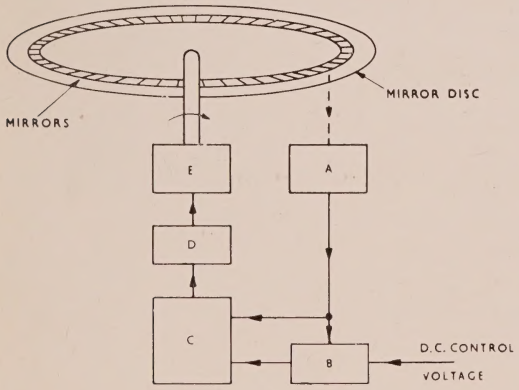


Fig. 2. Simplified block diagram of servo-system

A, mirror-pulse generator; *B*, reference-time-interval generator; *C*, Time-interval comparator; *D*, servo-drive control-voltage generator; *E*, servo-drive for controlling disc.

MIRROR DISC

The mirrors are set on a circle of 14 in. diameter and each mirror is positioned to an accuracy of better than 4 sec of arc. This corresponds to a circumferential accuracy of about 4 μ (or 0·00015 in.) and, with a rotational period of 1·2 sec, to a time accuracy of about 4 μsec. The aluminized strips forming the mirrors are about 0·01in. in width, the timing accuracy being derived from the leading edge which is sharp and straight to an accuracy of 1 μ.

SERVO-DRIVE UNIT

The chief requirement for the servomotor is that it should provide a rapidy controllable torque at a low speed, with a power availability of 0·01 h.p., and for a number of reasons a phonic motor was chosen. The phonic motor has the advantage that, being synchronous in operation, it can easily be held at a very accurate speed for test purposes by exciting at a fixed frequency; on the other hand, in order to

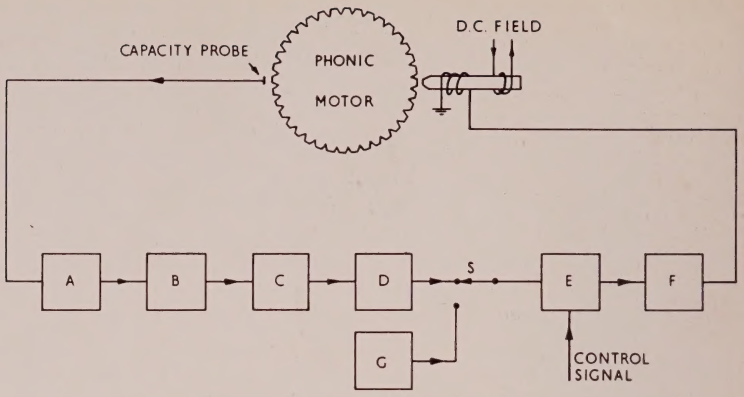


Fig. 3. Block diagram of motor control loop
A, pre-amplifier; *B*, waveform limiter; *C*, tuned filter; *D*, phase shifter; *E*, modulator; *F*, power amplifier; *G*, test oscillator.

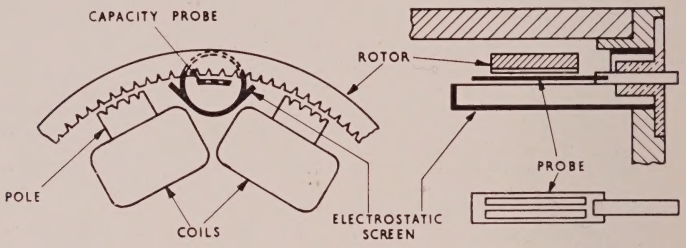


Fig. 4. Section of phonic motor showing details of the capacity probe and its relation to the rotor teeth.

obtain a controllable torque for servo purposes the excitation must be correctly phased with respect to the phonic teeth. This is only possible if it is derived directly from the motor itself; the method adopted uses a capacitance probe close to the phonic teeth.

In Fig. 3 the complete servomotor control-loop is shown. A pre-amplifier, A, amplifies the signal picked up by the capacitance probe shown in detail in Fig. 4. The signal is then limited to a square wave by a double-diode limiter, B, and restored to a sine wave by the tuned filter, C. A simple resistance-capacitance phase-shifter, D, is set to give the maximum motor torque. This setting can be done very simply by running the motor with constant excitation and observing the change of speed with phase. Aural means are quite adequate. Control of the motor torque is effected by varying the amplitude and sign of the current applied to the A.C. windings by the power amplifier, F. For rapid speed reduction it is necessary to reverse the phase of the exciting current. The modulator, E, passes a fixed signal sufficient to maintain the mean motor-excitation, and a variable signal which is proportional to the input control voltage. The modulator, E, consists of four triodes in a balanced circuit and utilizes the anode-characteristic non-linearity.

The phonic motor which was found to satisfy all the requirements was the Muirhead type A-816-C. A standard unit was modified to permit vertical operation and to incorporate a reduction gear-box and a 24 V D.C. motor and free-wheel drive for starting up. The motor operates best with an input frequency of 1 000 c/s for which the speed is 600 r.p.m.

CONCLUSION

The servo system and beat-frequency oscillator described above have now been giving satisfactory operation for over two years and have required no modification.

REFERENCE

The above described beat-frequency oscillator is more fully dealt with in a paper entitled 'The radio-frequency system of the Birmingham Proton synchrotron', published in the *Journal of Scientific Instruments*, Vol. 31, pp. 363–371, October 1954.

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JULY 1956

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VOLUME 10 **NUMBER 3**

JULY 1956

IN THIS ISSUE

Rig for Vibrating Centrifugal Impellers .. .. page 19
By D. A. Drew, B.Sc., A.M.I.E.E., A.M.I.Mech.E.

Magslips were originally developed at the Admiralty from Dr. C. V. Drysdale's phase-shifting transformers, and it is interesting to note that Magslip Resolvers made by this Company are being used as phase-shifters. An article on this subject appeared in *Technique* Vol. 4. No. 3. In this issue Mr. D. A. Drew describes a further application of Magslip Resolvers to the investigation of vibration problems of the famous Rolls-Royce 'Dart' airscrew-turbine engine.

Instructional Applications of the D-669-A Frequency Analyser .. .. .. page 21
By A. W. Keen, M.I.R.E., A.M.I.E.E.

The D-669 Frequency Analyser, when first introduced, was named Frequency Selective Amplifier Detector. However, it was very soon apparent that it had many other uses particularly in the field of vibration and general waveform analysis and the present title is more indicative of its versatility. Mr. A. W. Keen's article justifies the renaming by describing the many applications of this instrument in a school laboratory.

Book Review: 'Fixed Resistors' .. .. page 20

An Application of the D-638-B Muirhead-Wigan L.F. Decade Oscillator .. .. page 24
By K. G. Gill

THE FRONT COVER

The subject of our cover design is the D-729 Phasemeter; another of our versatile instruments recently introduced. Based on the principle that the vector-sum of two sinusoidal voltages is a function of the phase angle between them and their individual amplitudes, this instrument will measure the phase angle (0°—360°) and level difference (up to 70dB) of sinusoidal voltages presented to its two input channels. In addition, either channel may be used as a high impedance (30 megohm) thermionic voltmeter.

Other uses include:

Measurement of in-phase and quadrature components of a signal voltage.

Measurement of Q-factor using commonly available accessories.

Accurate measurements with seriously distorted waveforms may be made, using an external selective amplifier (D-669 Frequency Analyser) in conjunction with the Phasemeter.

D-649-D MUFAX RECORDERS
IMPROVED RECEPTION OF RADIO WEATHER CHARTS

The D-649-D Mufax Chart Recorder has always been arranged to use a 25dB contrast ratio when sub-carrier frequency-modulation (S.C.F.M.) and frequency shift signals are being received. It has been found that better copy, resulting from improved discrimination against radio interference, can be obtained with a 12dB contrast ratio. By means of a simple wiring modification the existing D-649-D Recorders can be provided with both 12dB and 25dB contrast ratios for radio working. The modification has been incorporated in the D-649-D/A and D/F Recorders.

We shall be pleased to supply details of the wiring conversion, to users of D-649-D equipments.

Relevant literature

Publication 7580—Muirhead Magslips

Publication 9737—D-669 & D-788 Frequency Analysers

Publication 9720—D-729 Phasemeter

Publication 4684—Muirhead-Wigan L.F. Decade Oscillator

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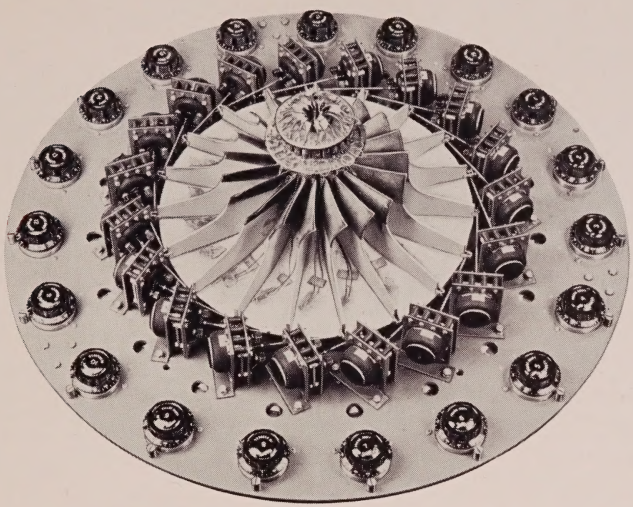
RIG FOR VIBRATING CENTRIFUGAL IMPELLERS

By D. A. Drew, B.Sc., A.M.I.E.E., A.M.I.Mech.E.*



MR. W. FRASER described in *Technique*, Vol. 4, No. 3, page 19, the use of Magslip resolvers for varying the phase of electrical signals. Rolls-Royce have used this principle in the investigation of the modes of vibration of the Dart turbo-prop compressor rotor.

The Dart engine employs a conventional single-sided centrifugal compressor whose rotor (or impeller) is surrounded by diffuser vanes (stator blades) equally spaced round its periphery. The important stresses in the impeller are excited by the 10 diffuser vanes giving rise to 10th, 20th and 30th vibration orders, i.e. vibration of the frequencies of 10, 20 and 30 times the rotational speed; by far the most important order is the 10th.

It is not practicable to consider the impeller as consisting of vanes joined to a back-plate and vibrating independently, the impeller must be considered as a whole. There are very important couplings between vanes via the back-plate. The interaction between adjacent vanes depends upon the phase relationship of their movements. The most obvious (and possibly the most dangerous) mode of vibration of an impeller is one in which most adjacent vanes move in contraphase. A very large proportion of centrifugal impellers has been designed with an odd number of vanes so as to avoid the possibility of all adjacent vanes moving in contraphase.

Strain gauge measurements show that there is a big variation in measured vibratory stress in going round an impeller from one gauge to another although these gauges are fixed in similar positions on each vane. This occurs with all impellers made to the manufacturing tolerances usual in the aero-engine industry.

Clearly all the parts of an impeller must be stressed at the same frequency at any one instant but a very small change in engine speed (and therefore of the exciting frequency) has a very great effect indeed upon the value of the stresses. It is necessary for the engine speed to be held within ·05% for any serious investigation of impeller stress amplitudes. Still finer limits are desirable for an investigation of the phase relationship between various parts of the impeller.

For exactly the same reason it was vital in a rig designed to simulate an engine to employ an oscillator whose frequency is stable to within ·05% from day to day. The D-105-A Muirhead-Wigan Decade Oscillator† was found to be very satisfactory for the purpose.

A very considerable amount of test data is available upon stresses in running engines obtained by strain gauges, the signals being brought out by sliprings. It was decided to investigate the effect of detuning some of the vanes from the remainder in order to determine the effect upon the stress distribution. Clearly this could be done far more easily under laboratory conditions where changes can be made to an impeller in a few minutes than under actual engine conditions with the necessity for stripping and rebuilding the engine in between changes. In the engine the excitation of the impeller is via the vanes at their outer extremities. A special rig was constructed embodying 19

†This oscillator is now superseded by the D-650 Muirhead-Wigan Decade Oscillator having improved accuracy and stability.

*Head of Vibration Department, Rolls Royce Ltd.

small electromagnetic vibrators attached to the outer extremities of the vanes in the plane of the tolerances in the manufacture of the impeller and it was the effect of these and of intentional

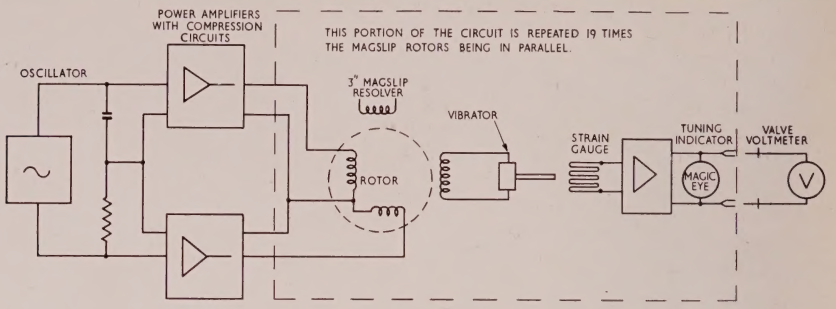


Fig. 1. Vibrator rig

impeller and tangentially to the outer diameter.

In order to provide excitation under laboratory conditions similar to those in the engine, it was necessary to supply the 19 vibrators with signals of identical frequency but of different and adjustable phase.

The output of a D-105-A oscillator was split into two signals in quadrature, the output of each being amplified in one-kilowatt public address amplifiers. Fig. 1 shows the arrangement diagrammatically.

The rotors of 19 Muirhead Magslip resolvers were fed in parallel from these two amplifiers, the stators being connected to the 19 electromagnetic vibrators. The phase angle between adjacent vibrators in order to excite the 10th order was: $360 \times 10/19 = 189°$

and for the 20th order:

$$360 \times 20/19 = 378° \text{ etc.}$$

Magic eye tuning indicators fed from 19 strain gauges on the vanes via 19 amplifiers, served to indicate the resonance of each vane and the whole set up was tuned by adjustment of the oscillator.

Maximum stresses in the various vanes occurred at slightly different frequencies due to variations in dimensions of individual vanes that the rig was designed to investigate. The stress distribution was examined quantitatively by means of a rectifier type voltmeter which could be switched to each gauge in turn; it was found that the stress distribution in the impeller excited in the rig agreed to within a few per cent of that obtained on the engine to which the impeller had previously been fitted and on which a very considerable amount of running data had to be obtained.

The importance of frequency stability in the oscillator will be appreciated when it is realized that the Q, i.e. dynamic magnification of the rig impeller, was as high as 2,000 and that measurements were made with an oscillator exciting the impeller on resonance where the amplitude change with frequency was considerable and where the phase change with frequency was very great.

The illustration on page 19 shows the impeller with its 19 exciters and the magic-eye indicators. The Magslips, which are not visible, are located immediately below the 19 dials together with the 19 strain gauge amplifiers. The strain gauge ballast resistors are symmetrically mounted in a circle immediately above the shaft.

NEW BOOK

Fixed Resistors by G. W. A. Dummer, M.B.E., M.I.E.E., Sir Isaac Pitman & Sons Limited, 1956, 28/-. First Edition 187 + XI pages. $8\frac{3}{4}$in. × $5\frac{1}{2}$in.

As Electronics invades each new field of human endeavour, demands arise for new components, and for better performance from existing types. Up-to-date information about manufacturers' attempts to meet the demands is usually difficult to assess, requiring specialist knowledge. It is therefore a great pleasure to see the first of a new series of textbooks on 'Radio and Electronic Components' written expressly for the user. This book, 'Fixed Resistors', sets a high standard for its successors to reach.

The nine chapters cover 139 pages, and it is gratifying to note that the longest chapter, of twenty-seven pages, is devoted to 'Measurements on Fixed Resistors'. Results of these measurements indicate the many characteristics required to be known before precision, or even reliable, electronic apparatus can be designed. Since carbon resistors form the bulk of electronic components today considerable space is devoted to their performance, and their voltage dependency is stressed.

Included in all the other chapters are numerous tables; whilst it is difficult to justify the inclusion of a chart of the colour code of all preferred values of resistors, occupying four pages, there is no doubt that Table 2.8 (for example)—'Summary of the Electrical Characteristics of Fixed Resistors'—more than makes amends for this verbosity.

continued on page 24

INSTRUCTIONAL APPLICATIONS OF THE MUIRHEAD D-669-A FREQUENCY ANALYSER

by A. W. Keen, M.I.R.E., A.M.I.E.E.*

THE frequency content of signals encountered in communication and control systems is of such fundamental importance that laboratory work in serious electronics and telecommunications courses should include accurate quantitative signal analysis. It may not be generally appreciated that the frequency-selective negative-feedback type of wave analyser which has been introduced commercially in recent years, primarily for vibration analysis, not only provides a convenient means of signal analysis, but is also a most useful tool for demonstrating and confirming all aspects of signal circuit theory and processes.

The Muirhead D-669-A Frequency Analyser is a particularly versatile form of this type of instrument. A functional diagram of the instrument is shown in Fig. 1, from which it will be seen to consist essentially of a calibrated input attenuator, a selective feedback amplifier and an accurate valve voltmeter in cascade. The amplifier may be switched to have a flat frequency response or tune sharply to any frequency in the range 30 c/s to 30 kc/s.

Over this entire range, which is covered in six closely calibrated bands, the Q-factor of the resonant response is constant and may be adjusted in value up to a maximum of 50. A useful feature is the ability to extract the output of the amplifier from a jack on the front panel.

Some of the more basic and important applications of the Frequency Analyser will be obvious to the user, notably measurement of the harmonic content of distorted audio signals, and resolution of non-sinusoidal (e.g. square) waves into their harmonic components. There are many other useful applications of the D-669-A. It forms an excellent indicator in coaxial and wave-guide test benches having a modulated r.f. source. It may be employed to convert a simple audio oscillator into one having superior performance by making use of the amplifier output jack: the D-669-A cleans up the oscillator waveform, improves the accuracy of the frequency calibration, and provides a monitored output amplitude.

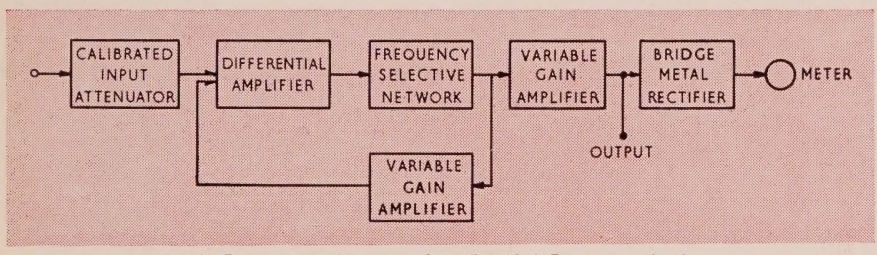


Fig. 1. Functional schematic of the D-669-A Frequency Analyser.

There are many occasions in the laboratory when the D-669-A proves useful as a flat amplifier or as an additional valve-voltmeter. It is also an aid in audio signal tracing, particularly in the location of hum and other spurious signals. The object of the present note is to describe briefly some instructional applications which have been developed in a technical college laboratory.

*Senior Lecturer in Electronics, Coventry Technical College.

MODULATION DEMONSTRATIONS AND MEASUREMENTS

One problem encountered in elementary communications courses is that of convincing students of the physical reality of the side frequencies produced by modulation of a carrier wave. This is most conveniently done at frequencies in the range covered by the D-669-A, using a carrier frequency in the region 10–20 kc/s with a comparatively high frequency modulating signal (say 5 kc/s), in order to facilitate separation of carrier and side frequencies. When a signal generator whose frequency coverage extends down to 20 kc/s is available, it is merely a matter of feeding its output into the D-669-A and tuning the latter through the frequency band centred on the carrier, first with modulation removed and then with modulation applied. Alternatively, the carrier may be produced by feeding two audio oscillators into a simple modulator circuit. The valve voltmeter 'peaks' at each component frequency, provided the modulating frequency is not too small, and may be used to measure the relative amplitudes of the carrier and side frequencies.

The same technique may be employed to analyse the behaviour of a variety of modulator circuits. It is particularly interesting to investigate the action of balanced modulators, such as that shown in Fig. 2. In order to obtain the textbook picture of the suppressed carrier waveform the modulating signal frequency must be tuned out (the twin-T RC network is most effective for this purpose), and higher-order side frequencies removed by the tuned anode circuit. By varying the valve operating conditions, relative amplitudes of the carrier and the signal, tuning of the carrier circuits, etc, and using the D-669-A to analyse the output signal, a comprehensive understanding of the circuit may be obtained. The D-669-A is very useful with this type of modulator in obtaining balanced operation, as indicated by minimum carrier component in the output signal.

With the advent of the new VHF broadcasting service of the B.B.C., technical colleges must give more attention to Frequency Modulation (FM). This development raises the need for experiments and demonstrations designed to bring out the nature of FM and necessitates a more profound treatment of modulation theory than was required for AM alone. The fact that an FM signal contains many pairs of sidebands of significant amplitude, even in the case of a simple sinusoidal modulating tone, calls for a wave analyser, and the D-669-A is suitable for this purpose, together with a frequency changer for translating the FM spectrum into the 30 c/s–30 kc/s range.

An important aspect of FM which may readily be demonstrated with the aid of the D-669-A is the variation of carrier amplitude with modulation index. Critical values of the modulation index, corresponding to the zeros of the Bessel coefficient amplitudes of the side frequencies, may be determined. One may employ a communications receiver of the type fitted with a beat frequency oscillator (BFO) for code reception, followed by the D-669-A (the audio filter provided in some receivers is not sharp enough for this purpose), or, if the available FM signal is large, a fixed frequency signal generator (as BFO), with a heterodyne detector. After tuning the D-669-A to the beat between the FM carrier and the BFO, modulation is applied and gradually increased in depth while noting the beat note amplitude on the valve voltmeter of the D-669-A.

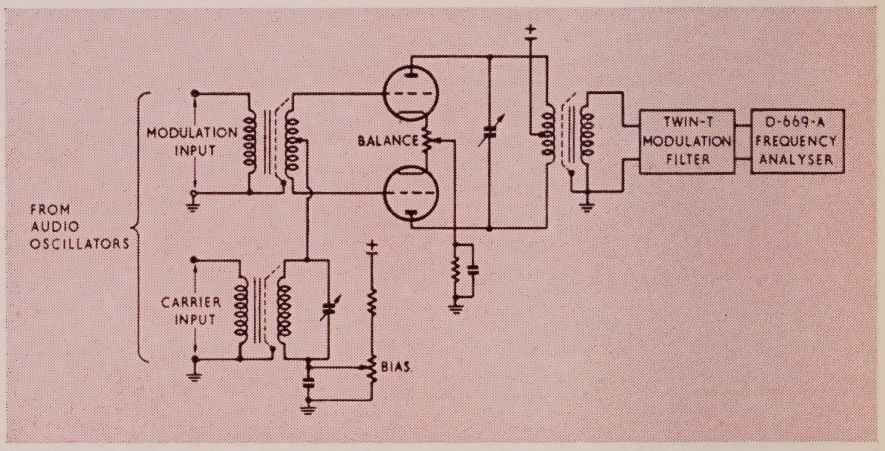


Fig. 2. A typical thermionic type balanced amplitude modulator.

REDUCTION OF DISTORTION BY NEGATIVE FEEDBACK

A simple experiment which demonstrates convincingly the beneficial effect of negative feedback in reducing the distortion occurring in an amplifier employs the circuit of Fig. 3.

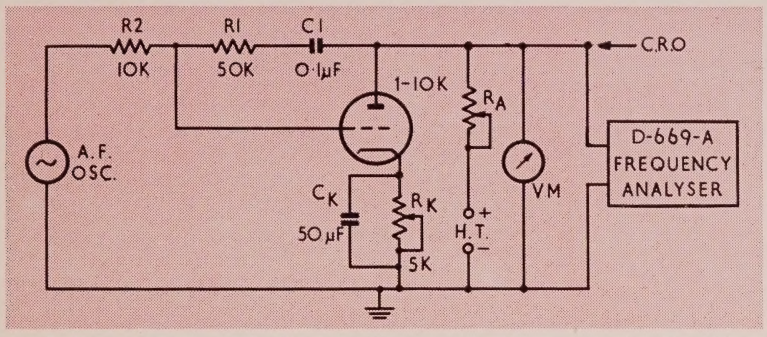


Fig. 3. Circuit of a negative feedback amplifier as used to demonstrate the effect of loop gain on external gain and distortion.

A single-valve amplifier having shunt-type feedback through C_1, R_1, R_2, is fed with a large constant amplitude sinusoidal signal from an audio oscillator, and the bias resistor increased, with the anode load resistor R_A at maximum, until appreciable clipping of the negative half cycles of input by bottom bend curvature of the valve characteristic is obtained, as observed on a cathode ray oscilloscope connected to the amplifier output. The D-669-A is used to measure the amplitudes of the fundamental and harmonic components of the amplifier output. The anode load is then reduced in steps, and the H.T. decreased at each step to preserve constant anode potential, thereby avoiding any change in valve parameters. At each step the fundamental and harmonic amplitudes are measured. When the results are plotted it is found that although the gain on the fundamental increases with loop gain (which is proportional to anode load when the r_a of the valve is comparatively high) and tends asymptotically to the ratio R_1/R_2 between the two resistors which determine the degree of feedback, the harmonic amplitudes fall and tend to zero.

OSCILLATOR INVESTIGATIONS

The D-669-A is particularly useful for investigating the frequency stability and waveform of oscillators. Instructional work on oscillator principles is more conveniently carried out at high audio rather than at radio frequencies. An excellent circuit for studying oscillator properties is the so-called Wien bridge (or Willans) type of RC oscillator, which has become well known as a result of its adoption by Muirhead in their range of audio oscillators. Its suitability is due to the broadness of the selectivity curve of its frequency-determining network, the low loss of this network (only 1/3 at peak frequency when equal C's and R's are employed), the incorporation of both negative and positive feedback paths, and the ease with which a variety of waveforms may be obtained.

In the circuit shown in Fig. 4 provision is made for variation of the gain of the maintaining amplifier as well as the degree of negative feedback. After plotting the gain and phase v. frequency characteristics of the frequency-determining network by itself, the network should be connected up to the amplifier circuit and the oscillation frequency and harmonic content of the oscillator waveform measured on the D-669-A at different levels of amplifier gain (positive feedback) and for different amounts of negative feedback at each level of gain. In this way a much more informative picture of the properties of this oscillator is acquired than could be obtained merely by observing waveforms on a CRO.

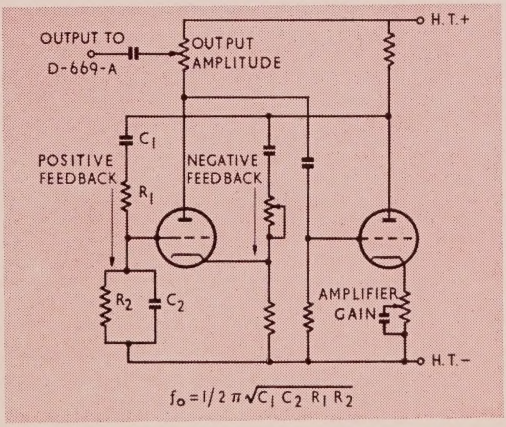


Fig. 4. The Wien bridge or Willans R.C. Oscillator.

AN APPLICATION OF THE D-638-B MUIRHEAD-WIGAN L.F. DECADE OSCILLATOR

By H. G. Gill*

DURING the course of a development programme at the Royal Observatory it was found necessary to construct an amplifier covering the band 58—62 kc/s and having a sharp cut-off outside these frequencies. It was decided that the amplifier should be constructed with stagger-tuned stages, and to obtain the optimum response over the desired band of frequencies it was necessary to aline the individual tuned circuits to precise frequencies. The scale of the signal generator available for this alinement was too coarse to permit the required accuracy of frequency setting, and the following method, incorporating the ease of frequency setting of the D-638 Muirhead-Wigan L.F. Decade Oscillator, was employed.

Figure 1 is a schematic diagram of the arrangement. A frequency of 60 kc/s, derived from a crystal oscillator, was used as the reference wave (f_r) in the measurements. This was combined with the output wave of a signal generator (f_s) and the resulting wave, pulsating in amplitude at the difference frequency of the two component waves, was displayed on one trace of a double-beam cathode ray oscillograph. The output wave of the Muirhead-Wigan L.F. Decade Oscillator (f_L) was displayed on the other trace and the time base locked to this wave. The frequency of the decade oscillator was set to the value of the frequency difference between the required tuning signal and the 60 kc/s reference frequency, and the signal generator tuned until the frequency of the beat pattern displayed was equal to that of the wave from the decade oscillator. Then:

$$f_s = f_r \pm f_L$$

There was no difficulty in distinguishing between these two frequencies and the continuous display of the frequency relationship on the cathode ray oscillograph enabled the frequency of the signal generator to be controlled within very close limits. This procedure was repeated while re-adjusting the decade oscillator to other required values of f_L, until the alinement was completed.

The D-638 Muirhead-Wigan L.F. Decade Oscillator contributes a quantity $\triangle f_L/f_s$ (where $\triangle f_L$ is the absolute error of the decade oscillator) towards the relative error $\triangle f_s/f_s$ of the signal frequency. In the above example the maximum value of $\triangle f_L/f_s$ was of the order of 5×10^{-5} and, in relation to this, the error contributed by the reference source could be neglected.

This method of improving the frequency setting accuracy of a signal generator has been used on several occasions, and little preliminary work is involved in setting up the apparatus since all the items are usually available as laboratory instruments.

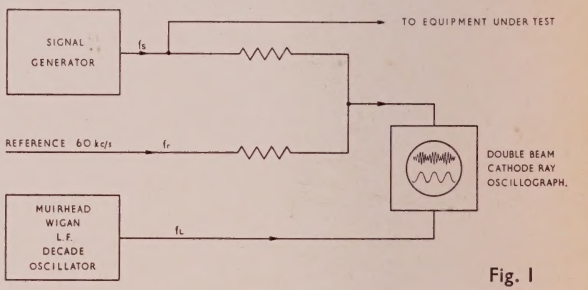


Fig. 1

*Royal Greenwich Observatory.

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NEW BOOK—(continued from page 20)

Different forms of resistor each occupy separate chapters, viz: General Purpose (having a resistance variation with load of 5 to 20 per cent): High Stability: Special Types: Experimental Types and Future Developments. Following these is a nineteen page Bibliography, subdivided in accordance with the chapters.

Finally there is a twenty-five page 'Comparison Chart of Representative Types', and a three-page book index. The chart gives data of the main characteristics of various types, grouped under three headings, mechanical, electrical and climatic. Since there is a multiplicity of resistors available the author has restricted the lists to Service Types. This data is graded by a system of stars to enable a designer to select the most suitable type in the shortest possible time.

Each chapter gives full details of construction and performance of the type under consideration. Important information in the Chapter on General Purpose Types includes electrical contact materials as well.

Special types comprise high-value and non-linear structures. Thermistors, voltage-sensitive, and high frequency load resistors are described. The 'Experimental Type' chapter deals with printed circuits, a very important miniaturization development.

With its handy size the book should be widely read, and it can be recommended for the study of all types of resistors. A. COOPER

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By J. Bell, M.Sc., M.I.E.E.

THE FRONT COVER

The cover design illustrates Industrial Weston Reference Cells which are an addition to our present range of Weston Standard Cells. Being of the unsaturated acid type, they have a low temperature coefficient of e.m.f. and negligible temperature hysteresis, features which are of great importance in the industrial field when wide and rapid changes in ambient temperature are likely to occur.

MUIRHEAD SYNCHROS

We are pleased to announce that further additions have been made to our range of Synchros made to U.S. Bureau of Ordnance Specifications. The following is a list of types which are now in production:—

Size 18 18CX4a Control Transmitter, 18CT4a Control Transformer, 18CDX4a Control Differential Transmitter, MK8 MOD O † Servo Motor.

Size 15 15CX4a Control Transmitter, 15CT4a Control Transformer, 15CDX4a Control Differential Transmitter, MK7 MOD 1 Servo Motor.

Size 11 11CX4a Control Transmitter, 11CT4a Control Transformer.

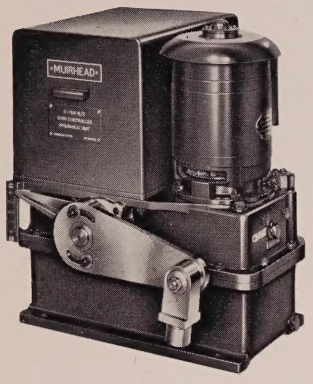
†In the interests of standardization we are preparing to discontinue the manufacture of the MK 8 MOD O motor and substitute in its place the MK 8 MOD 1 version. The performance of these two motors is identical, but the latter has an integral pinion having 15 teeth 96 D.P. in place of the 21 tooth 120 D.P. pinion of the MOD O version. Data sheets describing the MK 8 MOD 1 motor are available on request.

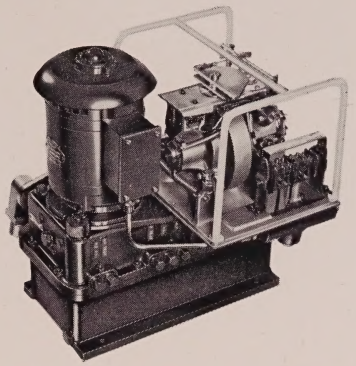
Relevant Literature

Publication 7730 D-768 Gyro Controlled Hydraulic Unit
Publication 7612 D-459 Differential Electro-mechanical Relay
Publication 5739 D-845 Industrial Weston Reference Cell

STABILIZING GEAR FOR SMALL SHIPS

By J. Bell, M.Sc., M.I.E.E.*





D-768 Gyro Controlled Hydraulic Relay

SHIP stabilizing gear employing the Denny-Brown system started with a medium size vessel, namely, the *Isle of Sark*, in about 1937. In 1938, the *Bittern*, one of H.M. Sloops was also fitted with this system; the writer was associated with the tests and improvements of the control and in the course of the succeeding three years, the basic control gear used in the stabilizer for more than 100 vessels at the present time was evolved.

An article describing this equipment as applied to the stabilization of the larger class of ship appeared in *Technique*, Vol. 9, No. 1.

In 1951 Vosper Ltd. of Portsmouth approached Muirhead & Co. regarding the possibility of fitting stabilizers in small vessels of say, 100 tons, either of the private yacht category or small naval vessels. It was appreciated that compared with the vessels previously fitted, the control gear must be more compact and less expensive and also that the fin gear itself should be designed to be as economical as possible in construction and operation. Co-operation on this development with Vosper Ltd. has continued and the result has been that a practical form of ship stabilization for small vessels has been evolved; while Muirhead & Co. are entirely responsible for the control used, the problems jointly considered were not limited to this aspect of the problem.

†References to the results achieved have appeared in certain periodicals, but it is thought that this presentation of the subject, particularly from the control aspect, would be valuable.

The control is based on the use of the Hydraulic Relay Muirhead Type D-696 which was described in *Technique*, Vol. 10, No. 1. In this article the pilot valve of the relay is described as being operated from a Magslip hunter, and an allusion is made to the possibility of alternatively controlling the pilot valve directly from a gyroscope; this is in effect what has been done. The upper case of the hydraulic relay is replaced by a compartment, housing a motor-driven gyroscope. The gyro-wheel is mounted so that it is responsive to the rolling velocity of the vessel, and the deflexion from a central position stretches centralizing springs by an amount proportional to the rolling velocity. The motion operates the pilot valve through appropriate linkages. Provision is made for varying the sensitivity of the control by altering the ratio between the angular tilt of the gyro and the movement of the pilot valve. This effectively alters the output of the hydraulic relay which is proportional to the input over its full range of operation. Combining the gyro and the hydraulic relay in one unit achieves the object of reduction in size and economy in price, although it does sacrifice certain refinements of control provided by the equipment fitted in larger ships. It is for this reason that Vosper Ltd. refer to the stabilizer as a means of roll damping rather than as a stabilizer.

The class of vessel for which this control is intended has a range of periodic time of natural rolling considerably shorter than the larger ships. It may be as short as three seconds, and ten seconds may be regarded as the longest time to be catered for.

Wave slopes encountered by a vessel may range up to 9 or 10 degrees in extreme cases, but a stabilizer or roll damper of sufficient power to counter such waves would be unduly expensive, and it has been found that fins capable of giving a steady heel of even two degrees in still water will provide a useful amount of

*Chief Research Engineer, Muirhead & Co., Limited

†*Shipbuilding and Shipping Record*, September 1955 *The Motor Ship*, October 1955 *British Engineering*, January 1956 *Shipping World*, April 1956 *Ship and Boat Builder*, May 1956 *The Motor Boat and Yachting*, May 1956 *Yachts and Yachting*, May 1956

damping, but that an installation giving 5 or 6 degrees is adequate for dealing with any but the most exceptional conditions of roll.

In order to achieve smooth working of the stabilizer, it is essential to have proportional control; thus, for a given roll velocity as measured by the gyro, a given angle of tilt of the fins is required. (The tilt angle of the fins is related proportionally to the heeling angle of the vessel in an efficient design.)

Taking for example a proportional control over say 3 degrees of heel and assuming simple harmonic motion of the vessel having a rolling period of five seconds, the maximum tilt of the fins corresponds to a rolling velocity of 3·8 degrees per second. While this illustrates the order of the sensitivity, a greater sensitivity may be employed depending on all of the parameters in a given case; the stability of the gyro to ship mounting, the rigidity of the fin operating gear etc. Too sensitive a setting of the control results in excessive and rapid movements of the fins, particularly under conditions of light rolling. The normal setting should be about 30% less sensitive than the setting at which such movements are observable.

The speed of the vessel, if it is stabilized by fins reacting with the water, must have an influence on the character of the response produced. In fact the damping force or torque produced on the vessel by fins varies as the square of the speed. Thus a vessel whose maximum speed is, say 14 knots, and whose stabilizer is designed to counter a wave slope of 5 degrees at that speed, will be capable of countering only a $2\frac{1}{2}$ degree wave slope at 10 knots. Operation of the vessel, therefore, at the higher speed will give better results, and it is in line with actual experience that it is possible and beneficial to operate a vessel which is stabilized at a higher speed than the same vessel unstabilized and rolling heavily.

When adjusting the sensitivity of the control to optimum operating conditions, the vessel should be travelling at full speed; operating subsequently at lower speeds sacrifices a little in sensitivity, but no instability of control will occur.

The control may also be used for 'forced rolling' of a vessel by merely reversing the linkage in the gyro unit. Some caution should be exercised however, if this is done, and all movable objects should be 'secured' before forced rolling is commenced as the results are liable to be spectacular.

Further points considered in the design of the equipment were, for example, whether the fins should be capable of retracting within the vessel, whether they should be fins of low or high aspect ratio, and whether the fins should be fitted with flaps or alternatively be simple aerofoil sections. The case for the stabilizer in a particular vessel often needs special consideration, but in general it appears that, for a small vessel, non-retractable fins of the simple aerofoil section offer the best solution to the problem. The actuating gear for tilting the fins must also be as light and economical as possible and the type of hydraulic actuator developed for aircraft use was adopted as being both light in weight and economical in space.

The first installation was carried out in the Vosper experimental yacht *Sea Victory* and subsequent installations have been made in other yacts of somewhat larger size up to 350 tons.

The general scheme of operation is shown in Figure 1; this figure is diagrammatic in that it does not contain all the details of the Control, but the essentials are indicated. The Gyro Controlled Hydraulic Relay can be operated from either an a.c. or d.c. supply, the motor driving the local hydraulic pump being of the order of $\frac{1}{8}$ h.p. or rather less. The mechanical output from this relay is normally 40 lb. acting through $\pm 1\frac{1}{4}$ in. Mechanical linkages couple the relay to the hydraulic actuators, which operate the fins; alternatively, electrical links (Magslips) could be used.

A separate oil supply is provided for the actuators, the hydraulic pump being driven from the main propulsion engine of the craft. It is essential to keep the two hydraulic systems separate because the pilot valve of the hydraulic relay must have oil of a high degree of cleanliness in order to function correctly from the small force available from the Gyro.

An illustration of the first experimental gear installed in the *Sea Victory* is shown in Figure 2 in the lower right hand corner of which can be seen the inboard end of one of the fin shafts and also the hydraulic actuator. The connecting shafts and lever between this and the Gyro Controlled Hydraulic Relay (Experimental pattern) which is upper left in the picture can readily be seen. A recorder of 'roll and fin motion is seen in the middle of the picture on

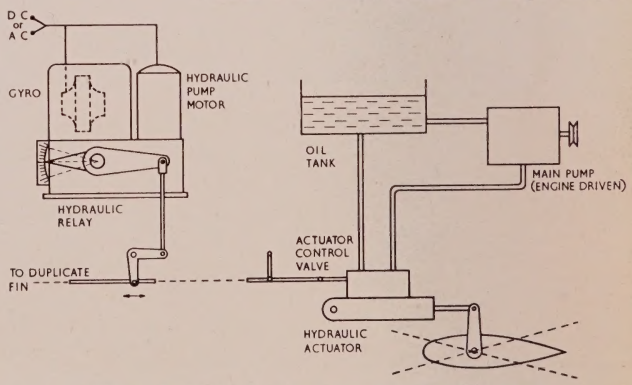


Fig. 1. Stabilizer equipment — functional diagram

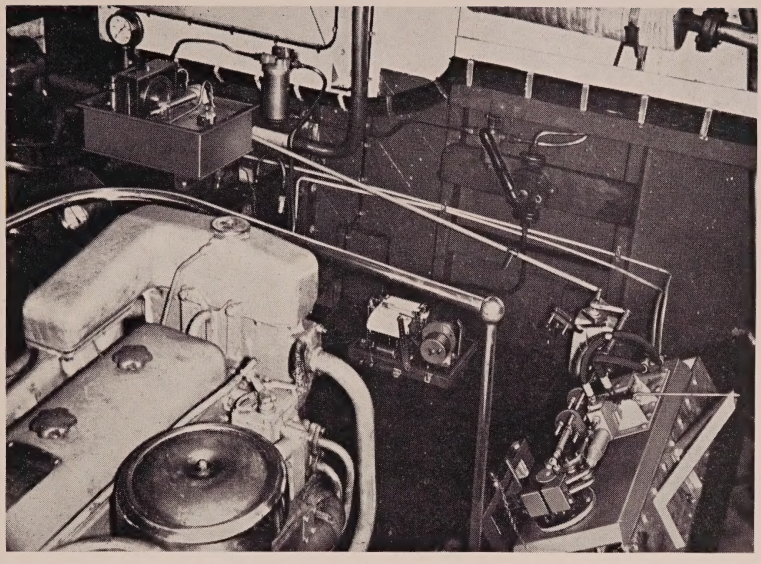


Fig. 2. Prototype equipment installed in M.Y. Sea Victory

the engine room floor. A record of stabilization and 'free rolling' is shown in Figure 3. The upper curve is a record of the fin movement. It will be seen that the fins are not working all the time to their maximum tilt, but they have effected a distinct reduction in the movement of the vessel. In this installation, the fins were rather smaller than desirable for dealing with heavy weather, but in the example shown with light rolling, adequate damping is available.

As an indication of the degree of comfort experienced when a Stabilizer is fitted, it might be interesting to recall an occasion at which the writer was present. The day was fine and, when in Portsmouth Harbour, there appeared to be insufficient sea for adequately testing the gear; nevertheless, the vessel proceeded into the Channel. Beyond the Nab Tower a swell was encountered, with the sea running approximately at right angles. There was just sufficient wind to cause small 'white horses' to appear. Under these conditions the *Sea Victory*, which is a former 'B' Class Fairmile M.L. was rolling quite freely, and tests were made with and without the Stabilizer. As lunch time drew near it was obvious that under normal conditions a satisfactory meal could not have been taken unless the vessel was brought to the lee shore of the Isle of Wight for some protection. As it was, the Stabilizer was left in operation continuously and the party sat down to lunch and ate and drank what was set before them without any difficulty whatever. It was remarked that this would be a tremendous advantage for the cruising yachtsman who, although he may like a little rolling now and then, just to know that he is in a ship, prefers his meals and sleep in comfort, particularly on a long passage where the fatigue experienced by contending continuously with a moving vessel reduces the pleasure of the trip and may even cause him to hazard his ship.

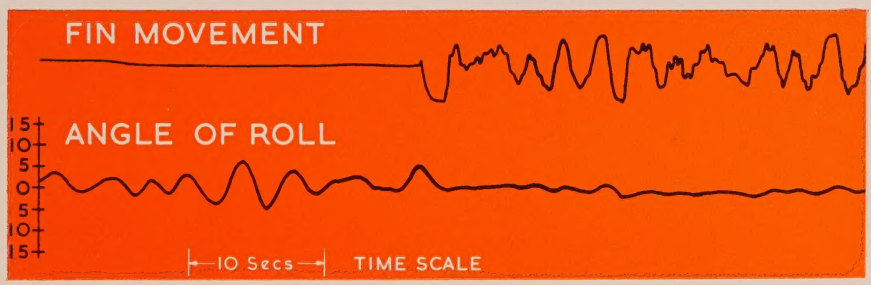
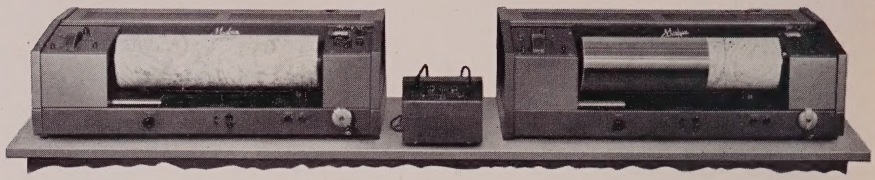


Fig. 3. Records of roll and fin action – Sea Victory. Wind S.S.W. 15-18 knots; Sea 2-4 Beaufort Scale

SEQUENTIAL TRANSMISSION OF METEOROLOGICAL CHARTS



WITH facsimile transmission it can be accepted as a generality that the dimensions of the picture drum dictate the maximum size of the material to be transmitted. This note describes how, with a little imagination and a minimum of modification, transmitters of a standard type have been adapted to transmit in sections and the recorder to receive *as a whole*, material too large to be accommodated in one piece on the picture drum.

This requirement has arisen in connexion with the Canadian Weatherfax system.* The Muirhead D-658-G Chart Transmitter and the D-649-G Chart Recorder with which the system is equipped were designed to handle meteorological weather charts having the dimensions 22 in. × 18 in., and consequently the transmitter was provided with a picture drum 22 in. long and 6 in. diameter upon which charts of these dimensions could be conveniently accommodated. A chart of this size can carry a map of the North American continent together with the required meteorological data in characters sufficiently large for reliable reception by the facsimile recorder. However, with the increase in range and speed of modern jet aircraft it was found necessary, in order to provide adequate weather forecasts for pilots and navigators, to include in the map a considerable portion of the Atlantic Ocean adjacent to the eastern seaboard of the continent. To meet this requirement, either a map of the same size but to a smaller scale or a map to the original scale drawn on a 30 in. × 18 in. chart would be required. The smaller scale map was thought undesirable on account of reduced definition although it could be transmitted normally from a standard machine. On the other hand, the larger chart could only be transmitted if cut into sections, each part sent separately and the received sections carefully joined to provide a facsimile of the original chart; obviously, this method would be laborious and time-consuming. To enable machines already in service to be used, and at the same time provide facilities for transmitting the larger charts without delay, the 'Sequential' system was introduced.

SEQUENTIAL TRANSMISSION

Sequential transmission is effected by two identical transmitters (D-658-G/B) arranged to co-operate with each other to maintain continuous transmission. Thus, when one machine reaches the end of a transmission it is automatically disconnected from the line and simultaneously, the second machine is connected and transmits in its place. While the second transmission is proceeding, the first machine may be reloaded and will again commence transmission at the instant that the machine on the line has finished. At the receiving end this results in a continuous record 18 in. wide.

Transmission by this method may be carried on indefinitely (within the limits of stability of the fork oscillators controlling the synchronism of the transmitter/recorder system). In this respect it can be said sequential transmitters perform the functions of a transmitter employing flat bed scanning, without the complex optical and mechanical systems that are inherent in this type of machine.

A satisfactory system has been achieved with two D-658-G/B transmitters and a D-789 Switching Unit.

The transmitters are a further development of the D-658-G machine: they are provided with means of maintaining the picture drums in continuous synchronism and phase, and an electromechanical device which operates the traverse starting mechanism.

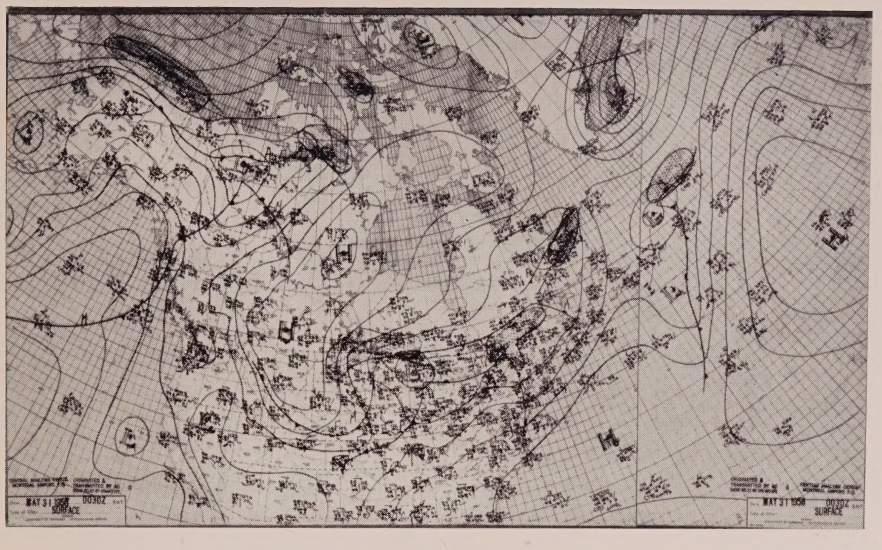
The Switching Unit embodies a system of relays which, in conjunction with certain relays in each of the associated transmitters, effect the change-over from one transmitter to the other as outlined above. The switching is arranged so that whenever a machine is off the line, the output circuit is terminated with an appropriate load resistor. Additionally, provision is made for maintaining both of the transmitters in the standby condition during quiet periods, and also for operating either of them manually in the normal manner when sequential transmission is not required.

The controls are few and simple consisting of a selector switch marked AUTO-MANUAL-STANDBY and two push buttons associated with the slave and master machines respectively which are operated, when the selector switch is set to MANUAL, to connect the appropriate transmitter to line. An indication of which transmitter is connected to line is given by a pair of green lamps located to the left and right of the selector switch.

The illustration shows the two D-658-G/B Transmitters with the D-789 Switching Unit conveniently placed in a central position.

Fig. 1 is a reproduction of a 30 in. × 18 in. weather chart recorded by the sequential method.

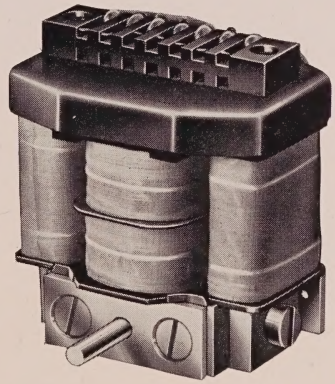
*Described in 'Technique' Vol. 8, No. 4, October, 1954



D-459 DIFFERENTIAL ELECTRO-MECHANICAL RELAY

J. Bell, M.Sc., M.I.E.E.*

THIS relay has been manufactured for a number of years now by this Company. It was introduced to meet the demands of the Service Departments for a relay to be used as a servo link in guided missiles. The design is based on a relay of German origin that was embodied in the V2 rocket missile.



METHOD OF OPERATION

The sectional drawing (Fig. 1) shows the general construction and from it can be seen the method of operation. The core material and the armature (which is mounted in ball bearings) are both made of high performance nickel iron alloys. The two outer limbs carry polarizing coils energized from a d.c. source and arranged around the armature is a coil former on which may be wound a number of coils connecting to circuits to which the relay is required to respond. The path of the magnetic flux due to the d.c. current is indicated by arrows, and under conditions of balance there

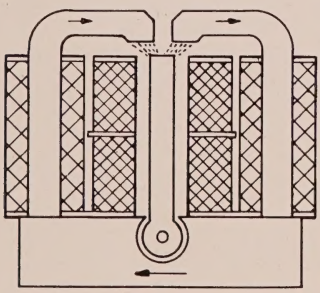


Fig. 1

*Chief Research Engineer, Muirhead & Co., Limited

is no flux passing down the length of the armature. The armature is thus held in a central position by the magnetic flux passing from one polarizing core to the other via the tip of the armature through the small air gap. The nett excitation given to the armature by the operating coils will cause a flux to pass through the armature and unbalance the flux which was maintaining the armature at zero. A deflexion of the armature is thus caused or alternatively a force is produced and such deflexion or force is substantially proportional to the exciting current.

SPECIAL CHARACTERISTICS

Due to the construction of the relay in which only the iron part moves, a reasonably high efficiency of response to current is realised. Furthermore, due to the small magnetic hysteresis of the material of which the armature and cores are made, the mechanical hysteresis of the relay is also small. The actual deflexion of the armature under controlled conditions is ± 1 degree and the value of the hysteresis is required, on final testing, to be not more than $2\frac{1}{2}$ minutes of angle. As an indication of the efficiency of torque output, one ounce inch is available for a control current of 1·5 mA in a 3300 ohm coil (7·5 mW) and the maximum of 10 ounce inches is generated by a proportionally larger current.

The frequency response characteristics of the relay with constant applied voltage are given in Fig. 2. The curves show the response with the armature free and unloaded (1) and with a loading equivalent to the inertia of a valve (2) used in the Muirhead Type D-696 Hydraulic Relay Unit, a description of which appeared in January 1956 Issue of *Technique*, Vol. 10, No. 1. The lowest curve (3) indicates the change of phase, with respect to operating current, of the mechanical movement of the armature. Fig. 3 gives the performance of the relay when energised with constant current. It will be observed that with the additional loading (equivalent to 6 grams at 5 cms. radius) a resonance in the response curve occurs at about 40 c./s.

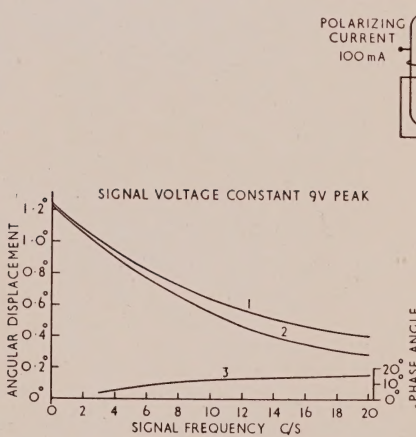
APPLICATIONS

This relay has been used by the Armed Services in many servo applications for operating the hydraulic or pneumatic valves in fire control apparatus, directors, gyro follow-up gear, etc. In the commercial field it has been built into a relay amplifier, described by J. H. Askew*, for direct operation from a Magslip or other control.

In this amplifier the armature of the relay is used to operate electrical contacts which in turn control the circuit for an electrical motor or other desired responding unit; the motor control can be either a d.c. or an a.c. type, and the reliability of the device is extremely good. Alternative circuits are shown in the paper referred to in which the relay is used in association with a stage of electronic amplification or rectification.

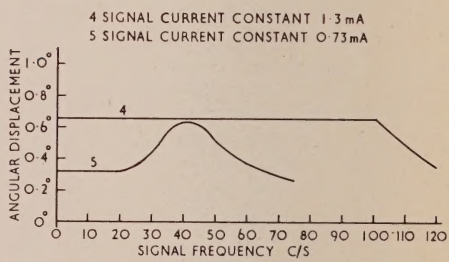
For certain applications it is desirable to balance the armature; this can usually be effected by appropriate design of the operating arm which should be attached securely to the relay spindle.

*Trans. S.I.T. Vol. 8



1 DISPLACEMENT/FREQUENCY–ARMATURE ONLY
2 DISPLACEMENT/FREQUENCY–ARMATURE + VALVE
3 PHASE/FREQUENCY–PHASE RELATIONSHIP BETWEEN SIGNAL CURRENT & ANGULAR DISPLACEMENT

Fig. 2



4 DISPLACEMENT/FREQUENCY–ARMATURE ONLY
5 DISPLACEMENT/FREQUENCY–ARMATURE + VALVE (THE VALVE MASS WAS 6g ATTACHED AT 5cm RADIUS)

Fig. 3

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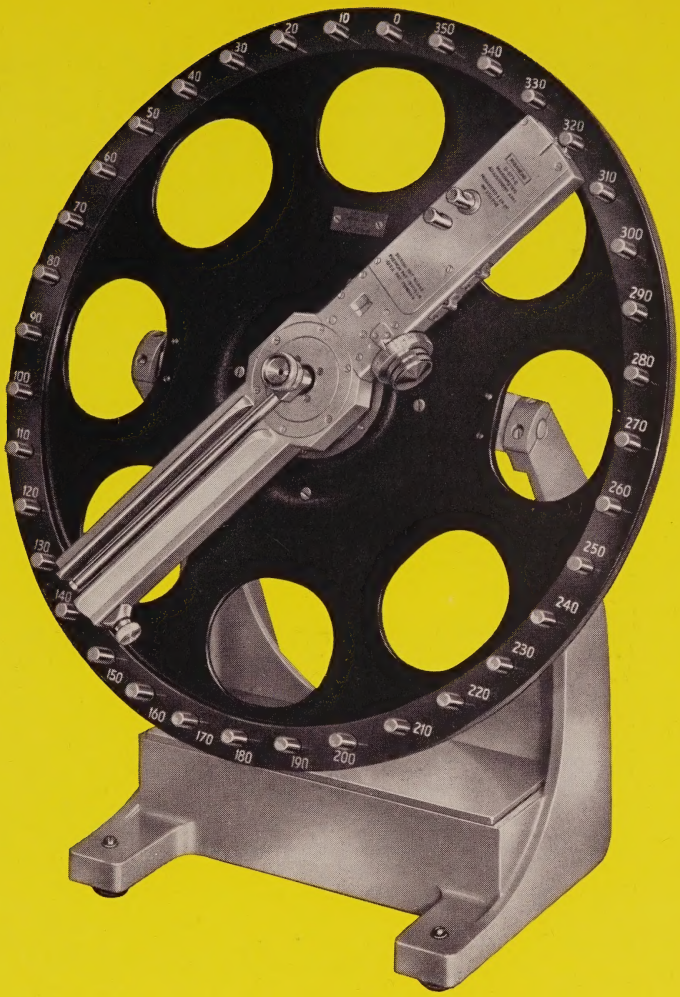

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By N. W. Simpson

We remind our readers that we publish a French edition of *Technique*.

THE FRONT COVER

The illustration on the cover of this issue depicts the D-725-C Synchro Test Fixture, part of a comprehensive set of test equipment for the complete electrical testing of CX, CT and CDX Synchro elements, designed for 115 V, 400 c/s operation, to U.S. Specification MIL-S-16892.

The equipment represents a sound investment for users as well as manufacturers, as by its use, complete acceptance tests may be carried out. It has been designed for use by relatively unskilled personnel and arranged for the convenience of the operator.

Relevant Literature, Publication 7741

MUIRHEAD SYNCHROS

In line with current U.S. policy we are discontinuing the use of the reference Bu-Ord together with Mark and Mod. numbers as qualifying terms for Synchros. Instruments made in conformity with U.S. Bureau of Ordnance drawings and specifications will be henceforward referred to as MIL Synchros. The designation of Servo motors by Mark and Mod. numbers will remain unchanged for the present.

In addition to the range of Synchros announced in previous issues of 'Technique', our production now includes the following MIL Synchros

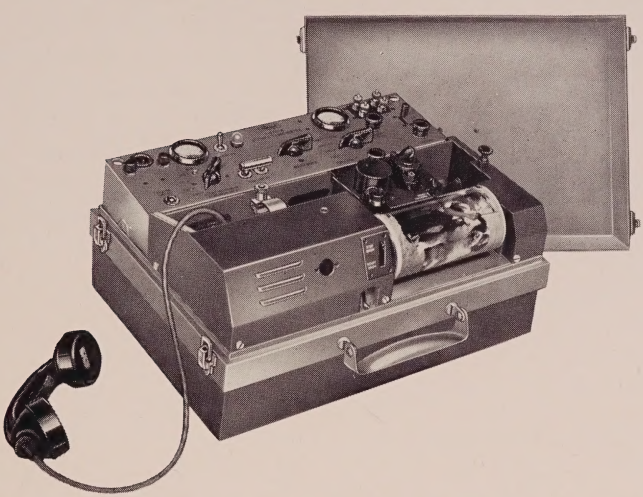
Size 15 15TR4a Torque Receiver 15TX4a Torque Transmitter

ANNOUNCEMENT

We are pleased to announce that our American Associates, Muirhead Instruments Inc., of 677 Fifth Avenue, New York 22, N.Y., have negotiated the sole representation for the territory of the United States, of the ADDISON ELECTRIC CO. LTD, Bosworth Road, London, W.10. This company specializes in instrumentation, quality control and automation for cable and wire manufacturers, and its products enjoy a world-wide reputation. They include the control of cable size, length, concentricity, corona, vacuum impregnation, etc. which have been applied, among many other important projects, in the manufacture of the new trans-Atlantic telephone cable.

THE NEW PORTABLE PICTURE TRANSMITTER (D-770)

By A. A. Kirchel* and P. W. Sieber*



MODERN newspaper industry depends more and more on pictures of national and sporting events to add interest to the daily news columns, and phototelegraphy has for many years been the means by which news pictures are flashed by radio and landline from all quarters of the globe to newspaper publishing centres of large towns and cities.

The principles of phototelegraphy are well established, and there are many hundreds of machines installed today transmitting and receiving photographs of a very high quality over networks extending to many thousands of miles. The Royal Tour of Australia in the winter of 1953–4 was a fine example of phototelegraphy in action, when pictures of events taking place in Australia were published in British newspapers on the following day.

The need for portable picture telegraph equipment to link remote places with the established networks has always been apparent, and sets termed portable have been available for many years; but when one considers the weight of these equipments it is doubtful if the terminology is indeed true. The new Muirhead D-770 Picture Transmitter can be really classified as a 'portable' since it is complete in one case, weighs under 35 lb. and is sufficiently compact to be carried as personal luggage. All the facilities normally found on larger machines are provided, including a telephone handset for communication with the distant receiver, a loudspeaker for monitoring purposes and provision for 2-wire or 4-wire working. Pictures to a maximum size of 8 in. $\times 5\frac{1}{4}$ in. can be transmitted at 60 or 120 rev/min to any receiver conforming with C.C.I.T. recommendations. By a new approach to the design of both the mechanical and the electronic units, compactness and light weight have been achieved without any sacrifice of the high performance and reliability of other Muirhead transmitters.

All picture machines require a source of electrical power to enable them to operate, and to provide the maximum flexibility in this respect, the machine has been designed to operate either from a 6 V accumulator of ample ampere-hour capacity, e.g. a car battery, which is usually available on the site and need not necessarily be carried with the instrument, or from a 50 c/s single phase a.c. power line of any voltage in common use. Direct current power lines do exist, but so rarely that to provide for them would mean an unjustified increase in weight.

TRANSMITTER

The illustration shows the general layout of the transmitter. The picture drum is mounted at the front right-hand side and immediately behind it is the travelling optical carriage. This arrangement is more compact than the alternative method of scanning where the drum moves sideways in front of a viewing lens. Across the width of the machine and to the rear of the mechanism, is the control panel, which being of generous proportions allows the knobs of the operating controls to be large and convenient to handle; the meters located on the panel are clearly marked and easy to read. The control panel is hinged along its front edge to allow easy access to the electronic chassis immediately below. To the left of the drum the loudspeaker is housed behind a grill, and also in this location, remote from the heat generated by the motor alternator and the electronics, is

*Muirhead & Co. Limited

placed the tuning fork used for synchronizing purposes. Space is provided behind the loudspeaker for stowage of the telephone handset and all connecting leads when the transmitter is not in use.

The size of the scanning unit driving mechanism is commensurate with the amount of work expended in revolving the picture drum and moving the optics carriage; the gear train connecting the drum to the motor drive is quite miniature and resembles clockwork in its proportions. The leadscrew which feeds the optics carriage, being quite short in length, is reduced in diameter as far as is possible without impairing its stiffness.

The major advance in the design of the new transmitter, contributing most to the reduction in size and weight as compared with previous models, is the provision of a miniature fork-controlled motor-alternator which provides both a synchronous drive for the mechanism, and a stabilized output for the supplies to the electronics. This assembly comprises a low voltage a.c./d.c. motor and two alternators, the motor being operated from a 6-volt battery or, in the case of mains operation, from an output of the mains transformer. Both alternators produce outputs at 1020 c/s with the motor running at the synchronous speed of 5100 rev/min. One alternator is employed as a variable brake to synchronize the motor (synchronizing alternator) and the other produces an output at a constant voltage due to the unvarying speed of rotation (supply alternator).

SYNCHRONIZATION

Synchronization of the motor is effected by a control circuit which compares the alternator frequency with that of the standard 1020 c/s fork, and adjusts the loading of the synchronizing alternator according to the phase relationship of the two frequencies. Initially, the motor speed is adjusted by means of a rheostat connected in the motor supply so that the alternator current produces a mid-scale deflexion on the synchronizing meter corresponding to the mid-point of the synchronizing range (Fig. 1). In this condition the alternator frequency is synchronous with the fork frequency and the alternator voltage lags the fork voltage by approximately 90°. If the motor speed should tend to increase either due to an increase in the supply voltage or due to a reduction in the mechanical loading, the angle of lag will decrease, the current drawn from the alternator will be greater and the motor speed will be maintained constant by the increased loading of the alternator. Conversely, if the motor tends to slow down, the angle of lag is increased, the loading of the synchronizing alternator is reduced and the motor speed remains unchanged. The synchronizing range caters automatically for supply voltage fluctuations of up to ±5% and there is no tendency for synchronism to be lost when the drum is engaged at 120 rev/min. A stroboscope provides visual indication of synchronism and may be viewed through an aperture at the front of the machine.

As previously stated, the output from the supply alternator feeds the scanning lamp and provides high-tension supplies for the valves and the photomultiplier. Use of the comparatively high frequency of 1020 c/s has distinct advantages over the normal 50 c/s supply in that the transformer and smoothing compo-

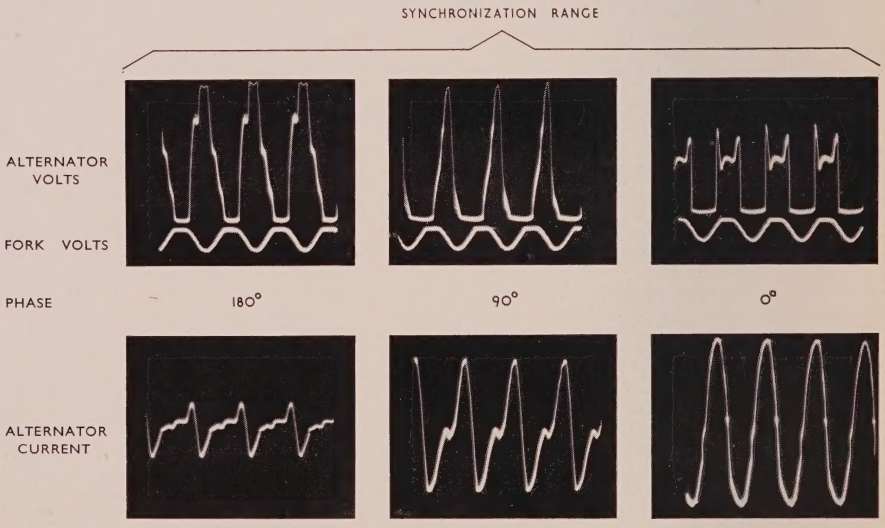


Fig. 1. Oscillograms showing phase relationship between alternator volts and fork volts with corresponding alternator load current.

nents are greatly reduced in size and weight. The 1020 c/s output obviates the need for rectifying and smoothing the supply to the scanning lamp since, due to thermal inertia, the filament does not respond to frequencies of this order.

OPTICAL SYSTEM

Another feature of particular interest is the compact optical system. Scaling down of existing optical heads would not have been satisfactory since the tolerance to radial movement of the scanned surface would have been reduced, resulting in dark areas being produced on the received copy in places where the original was not in intimate contact with the drum. In the system employed, a greatly increased tolerance is obtained by arranging that the beam of light illuminating the scanned area and that of the diffused light collected by the objective lens are on the same axis (see Fig. 2). This feature is of particular advantage with a portable transmitter where the originals are frequently prepared in the field, and being unglazed are sometimes difficult to wrap tightly round the drum.

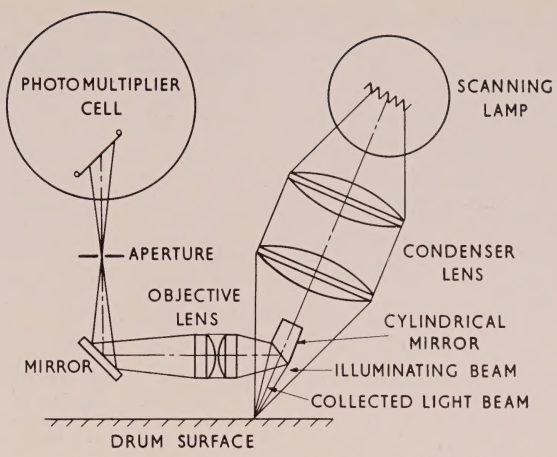


Fig. 2. Concentric optical system.

MODULATOR

The variations in tone of the picture elements are converted to an amplitude modulated signal for transmission over existing telephone networks. This conversion is effected by a novel balanced modulator, which comprises a single photomultiplier cell having two anodes, connected in a balanced circuit. In this arrangement the d.c. component is automatically suppressed and the balance cannot be affected by fatigue of the photocell. The use of a single photocell contributes largely to the compactness of the optical carriage.

For synchronizing purposes it is often required to transmit the 1020 c/s fork frequency as a modulation of the picture carrier frequency and in this transmitter the facility has been provided very simply by the addition of a small neon lamp situated in the photomultiplier cell housing. To transmit 'fork mod' as it is termed, the scanning lamp is extinguished and the neon lamp is excited from the 1020 c/s fork supply. The illumination varies at the fork frequency, producing the required amplitude modulation of the carrier frequency.

STANDBY CONDITION

A standby condition is provided in which, to conserve power during waiting periods between transmissions, the supply is removed from the motor. The loudspeaker remains operative so that the transmitter can be called by the distant receiver and the telephone handset provides a means of communication. On mains operation the h.t. supply to the loudspeaker amplifier is derived from an output of the mains transformer but in the case of 6 V d.c. working a small h.t. battery is employed solely to provide the loudspeaker facility in the standby condition.

CONCLUSION

In the choice of electronic components, reliability has been a major consideration. The mechanical parts, the general structure and covers, although light are sufficiently robust, particularly in view of the fact that the transmitter can be carried by the operator himself to avoid the possibility of really rough handling.

The design of the transmitter as a whole is a good compromise between miniaturization and dependability, and there is no doubt that this new machine will prove to be a very useful addition to the range of phototelegraphy equipment.

Relevant Literature, Publication 8725

THE USE OF MAGSLIPS IN THE RECORDING OF INFRA-RED ABSORPTION SPECTRA

By N. W. Simpson*

THE technique of Infra-Red Spectroscopy is now well established for chemical analysis both quantitatively and qualitatively. With the introduction of N.P.L. Merton replica gratings as cheap dispersing units[1] it is possible that the use of the Infra-Red Spectrometer will become more widespread, and a relatively cheap instrument has been constructed using one of these gratings. The optical system of the monochromator is based on a suggestion by J. L. Hales of C.R.L. Teddington, and the system of recording has also been described in detail by him.[2]

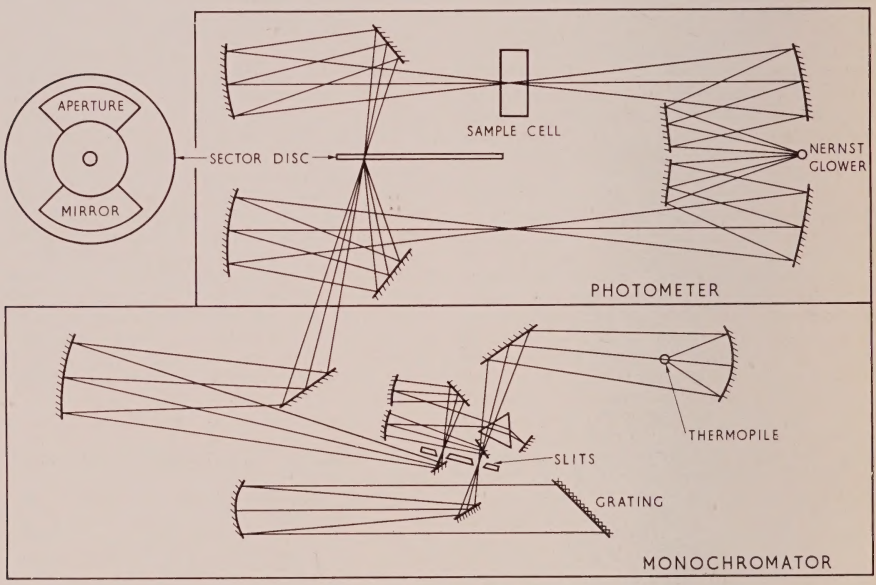


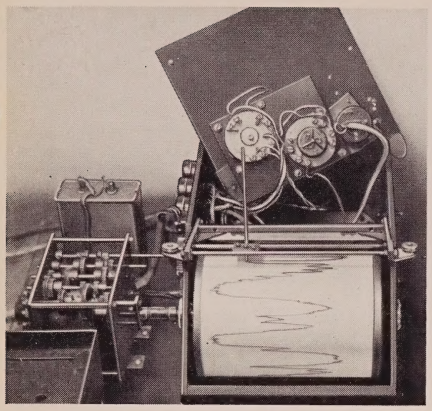
Fig. 1. Optical Layout of Spectrometer.

OPTICAL SYSTEM

Fig. 1 shows the schematic diagram of the optical system. Two beams are obtained from a Nernst filament used as an infra-red radiator, one beam used as a reference and in the other the sample for examination is placed. These are switched alternatively into the monochromator by means of a rotating sector disk, driven by a small electric motor at 4 rev/sec, which makes possible a double beam in time system of recording. This disk is divided into four sections. One has an aperture through which the sample beam passes to the monochromator, the second is blank and cuts off radiation, the third section has a mirror which reflects the reference beam into the monochromator, the fourth like the second is blank. Thus radiation of any wavelength falling on the thermopile detector comprises two conditions, one being the transmission of the sample, the other being the reference beam, and the resultant voltage will comprise two sequential peaks differing in phase by 180°, each being proportional to the radiation producing it. These two voltages are amplified by a common amplifier and then separated and rectified by a synchronous switch mounted on the shaft of the sector disk, two d.c. outputs being obtained from a pair of cathode followers and fed into a potentiometer recorder. Thus as the spectrum is scanned the ratio of the intensity of the two beams will be recorded.

Separation of the various orders of the grating is obtained by using a simple foreprism. This is coupled to the grating table via a cam enabling continuous recording from 2–15 μ, although for maximum resolution the grating is operated in the order most suitable to that part of the spectrum.[1] The layout of the monochromator enables three slits to be combined in one unit; they are built on the Sears principle and are

*Yorkshire Tar Distillers, Ltd.



The recorder with the panel removed showing the servo motor, induction generator and potentiometer. On the left is the gear-box which houses the synchronous link transmitter. The motor driving the drum is inside the case.

operated simultaneously by a single micrometer screw. One slit 25 mm. long serves as entrance and exit slits for the grating, the spherical mirror being used off axis in a vertical plane.

RECORDER

In designing the recorder, it was decided that a pen speed of 5 seconds for full scale deflexion would be adequate, since quicker speeds would be limited by the time response of the main amplifier and the signal rectifying system. The recorder, Fig. 2, was constructed around a three turn helical potentiometer, resistance 100 ohms, operated by a Muirhead E-16-A 2 in. Servo Induction Motor with an E-5 2 in. Induction Generator, the choice of servomotor being largely influenced by the following considerations. The load imposed by the potentiometer and pen on the servomotor is greatest under standstill conditions, being approximately $\frac{1}{2}$ oz./in. at the motor shaft. It is therefore preferable that the motor should have high starting torque, a requirement met by the E-16-A. This ensures that the time lag in recording changes in the spectrum is kept to a minimum, thus keeping the input to the servo amplifier within prescribed limits, avoiding overload and enabling the amplifier to operate at high sensitivity without automatic gain control. It was also found that the external magnetic field of the a.c. servomotor was less troublesome to avoid than the radiation from the commutator of a d.c. servo, which was quite easily picked up by the thermopile detector. Out-of-balance voltage in the potentiometer is fed into a balanced d.c. amplifier using high-mu pentodes operated as a longtailed pair. Thus, they are only sensitive to voltage variations between grids, the voltage amplification of each valve being 250. Output from the d.c. amplifier is fed into a balanced modulator using 50 c/s mains as a carrier. Various modulators have been used but the most successful, since it offers some measure of amplification, utilizes two 6F32 sharp cut-off pentodes. A common anode load is used and a push-pull 50 c/s voltage, 0·5 V grid-to-grid, is fed to the control grids, the suppressor grids being connected direct to the anodes of the d.c. amplifier. The 50 c/s output, therefore, varies in phase and magnitude with the out-of-balance voltage in the potentiometer.

Output from the balanced modulator is fed into a servo amplifier comprising a twin triode valve which mixes the control voltage and the voltage from the feedback generator; a pentode voltage amplifier tuned to 50 c/s by a parallel-T filter inserted in a negative feedback line, reduces the gain of the stage to unity at other frequencies. A single pentode power amplifier supplies some 10 watts to the control phase of the E-16-A Servomotor, which is coupled to the spindle of the helical potentiometer through a 45 : 1 reduction gear. A ball-point pen is attached to a cord which is passed round a drum on the potentiometer spindle: any movement can then be recorded.

The servo amplifier supplies maximum power of 11 watts to the motor under stalled condi-

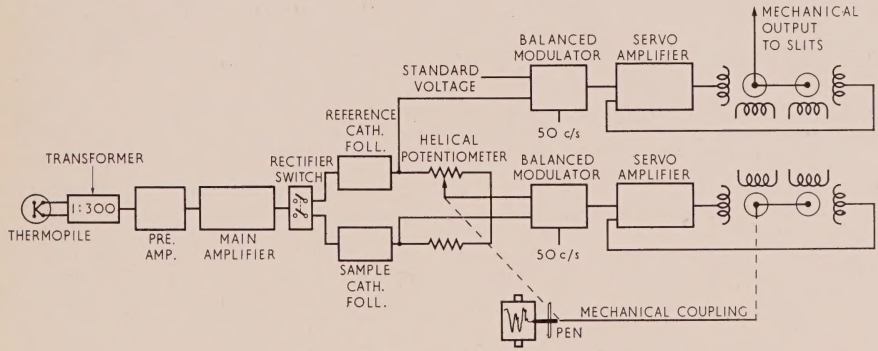
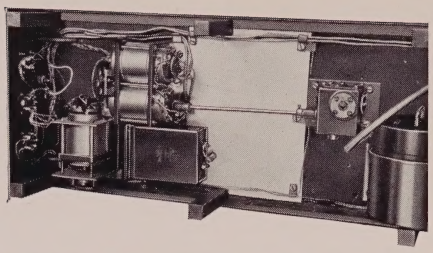


Fig. 2. Block diagram of amplifier and servo system.



Underside of monochromator showing the slit servo mechanism and the receiver of the Magslip synchronous link.
The detector, transformer and pre-amplifier are mounted at the other end to avoid 50 c/s pick-up.

tions, and this is produced for an error of 5%. Under running conditions with an error of 5% the power input to the motor is 9 watts, the motor speed is 1800 rev/min, giving a pen speed of 4·5 seconds for full scale deflexion. In practice, however, the speed of response is such that the error is never greater than 2%. A more elaborate servo amplifier has been used having automatic gain control and greater power output increasing the pen speed to 2 seconds, but the present simple arrangement has been found adequate. A nominal current of 3 mA is maintained in the potentiometer, a variation in sample beam intensity being equivalent to 3 millivolts. With only half the gain of the simple servo amplifier there is no difficulty in recording variations of this magnitude. Some drift of the d.c. amplifiers is experienced after initial switching on, but after this, drift is negligible.

The reference voltage is also an indication of the energy available at a particular wavelength for a given slit width, and this decreases as scanning is carried into the longer wavelengths. By comparing the reference voltage with a standard and feeding the difference into a balanced modulator, another stabilized servomotor is used to operate the slits, through a 300:1 reduction gear and thereby maintain a constant reference voltage. Since the same sensitivity is not required as with the recorder, further simplification is obtained. The pentode voltage amplifier is dispensed with and the twin triode combines both functions of mixer and tuned amplifier.

The recorder drum is coupled to the grating table through a gear box, which enables the wavelength scale to be expanded, and a simple synchronous link comprising two E-2 Magslip Synchronous Link Transmitter elements. This is driven by a d.c. shunt motor whose armature is connected in the cathode lead of a pentode power valve. As the current through the motor armature varies with the bias of the valve, the scanning speed can be controlled manually or automatically. Although not essential, automatic control has been found useful. Thus, if at high scanning speed the pen servo speed is not fast enough to follow the spectrum being recorded, the lag will result in a large out-of-balance signal to the servomotor. This signal is rectified and used to control the bias of the power valve, slowing down the scanning motor until zero balance is obtained in the potentiometer. Some slip is experienced with the simple synchronous link due to overload, but by maintaining constant load, i.e. employing balance weights instead of springs, this has been found to be constant.

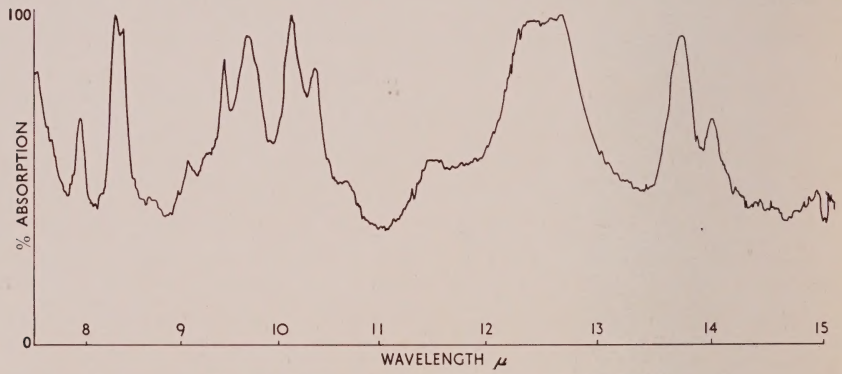


Fig. 3. Spectrogram of a commercial grade of 4 Methyl-pyridine.

The performance of the instrument is illustrated in Fig. 3 showing a double beam recording of the spectrum of a commercial grade of 4 Methyl-pyridine, 8–15 μ, being recorded in 20 minutes. Inexpensive spherical mirrors are used and thus for a comparatively small outlay a quite useful instrument has been produced.

References: [1]L. A. Sayce and A. Jackson, *Molecular Spectroscopy*, Inst. Pet. 1955
[2]J. L. Hales Journal Scientific Inst. Feb. 1953

Relevant Literature, Publication 7580

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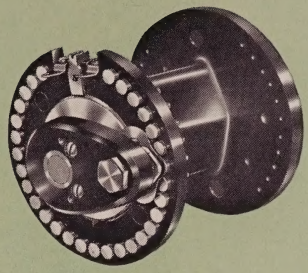

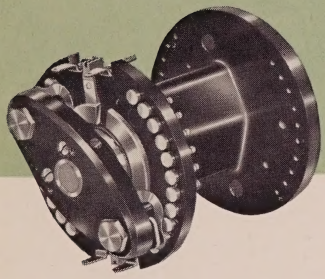

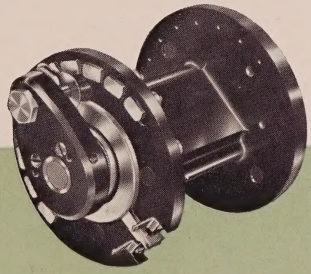

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IN THIS ISSUE

UNUSUAL APPLICATIONS OF MAGSLIPS .. .. page 3
By G. J. Trapp

The Magslip was originally developed for remote indicating and control purposes in the Royal Navy, and was subsequently used for similar applications in the other fighting services.

The problems that were solved in the Services by the use of Magslips have their counterparts in industry, and Magslips are now being widely used in many branches of production control. It is interesting to note that Muirhead Magslips are extensively used in the reactor control system of Calder Hall — the power station that puts Britain into the lead in the race to obtain economic power from nuclear fission.

However, there are some Magslip applications which are not generally well known, and some examples are described in this article. The author develops the Magslip from the polyphase alternator, shows how certain Magslip combinations are the electrical equivalent of the mechanical differential drive and concludes with a description of a recently developed Magslip — the Monodiff and some of its applications.

THE FRONT COVER

The weakest feature of an electrical instrument is frequently the switching system, and to ensure the continuous reliability of the equipment, relatively frequent attention to switch operation and cleanliness is required. Being both users as well as manufacturers of high-grade instrument switches, we have given much consideration to suitable contact materials and carried out a thorough investigation into the design features of rotary stud switches with a view to improving their reliability, reducing contact resistance and rendering them relatively free from the problem of maintenance.

In the type of switch employing sliding contacts one of the chief causes of failure is the accumulation of dirt that collects on the contact surfaces due largely to the necessity of using a wet lubricant. If this is not removed at relatively frequent intervals a semi-insulating film forms which results in high and varying contact resistance or even intermittent contact, while the abrasive property of entrapped dust particles causes excessive surface wear. Brushes designed to provide a self-cleaning action are only partially effective in preventing these troubles.

The rotary stud switches illustrated on our front cover — the construction of which was described in Vol. 9, No. 3 of this journal — employ silver-graphite moving contacts operating over silver-shod studs. Both of these materials have low specific resistances and the graphite component provides a constant dry lubricating medium for the contact surfaces. The efficiency of this design has been tested over many thousands of operations.

Relevant literature: Publication 6776-A.

PUBLICATION E-1000

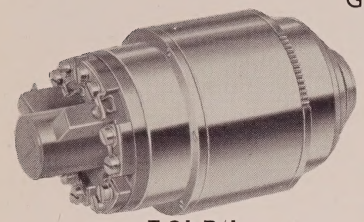
We are pleased to announce that E-1000, 'Muirhead Magslips — Applications and Methods of Use' is now available to all who are concerned with the design of Magslip Systems.

E-1000 is a 60-page book, well illustrated with line drawings and half-tone blocks. From the history of remote indicating devices, it outlines the development of Magslips and their theory of operation. This is followed by three chapters devoted to (1) Magslip Systems for remote indication and control, and servo mechanisms (2) the design of new systems and (3) the use of Magslips and associated devices for analogue computation. The electrical and mechanical aspects of Magslip elements are discussed in two further chapters, and the book concludes with an informative chapter on measurements, tests and fault location. A comprehensive subject index is included.

A copy is being sent to all holders of Muirhead Magslip Data binders, and also those who have sent a written request for this publication.

UNUSUAL APPLICATIONS OF MAGSLIPS

G. J. Trapp*



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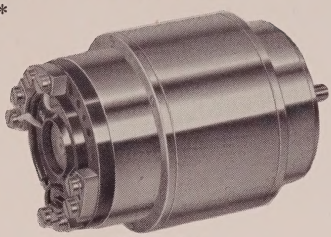

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THE regular applications of Magslips are now fairly well known and their industrial use is, in consequence, increasing. The Magslip is, however, an instrument of great versatility and the demands of modern instrumentation are many and varied; an account of some unusual possibilities with Magslips may therefore be of interest. A short account of the working principles is given first to facilitate a ready appreciation of the arrangements described later.

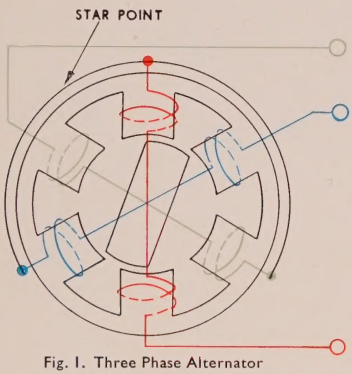

Fig. 1. Three Phase Alternator

WORKING PRINCIPLES

Fig. 1 shows a basic three-phase alternator having star-connected phase-windings which are individually coloured. If the permanent magnet rotor rotates at a uniform speed the instantaneous voltage induced in each winding varies with rotor position, giving the well-known three-phase voltage curves shown in Fig. 2, which have been coloured to correspond with the windings. The 0-degrees position of the curves of Fig. 2 lies on the horizontal axis of Fig. 1 and the curves are to be interpreted according to the instructions at the *left-hand* side of the figure.

In Fig. 3(a) the same alternator is shown, in simplified diagrammatic form, with its stator windings connected line-to-line with those of an exactly similar stator. When the rotor is driven the currents which flow in the second stator produce, by combination, a uniform magnetic field, whose axis is indicated by the arrow, rotating synchronously with the alternator field but displaced by 90°. The instantaneous direct voltages of the alternator stator windings, for the particular angular position of the rotor, are shown in the small voltage diagram at the right-hand side of the figure, coloured to correspond with the windings, the ordinate above the horizontal axis representing a positive voltage and those below representing negative voltages. If a rotatable permanent magnet is placed in the second stator, as shown dotted in the figure, then it will aline itself and rotate with the field. Since its angular position is always related to that of the alternator magnet the system forms a data transmission system but its effectiveness varies with speed and it ceases to function when stationary.

In Fig. 3(b) the same two machines are shown but the permanent magnet of the alternator is replaced by a wound rotor energized with a.c. and placed in a position at right-angles to the previous position of the permanent magnet. An alternating field is set up, so that alternating voltages now appear in the three stator windings; hence, although the individual stator voltages still depend upon rotor position, they no longer depend directly upon rotational speed and the system functions when stationary or when rotating at low speed. Where, in the former case, a stator voltage was positive or

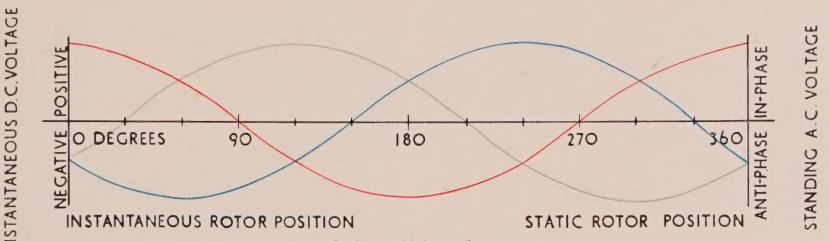

Fig. 2. Stator Voltage Curves

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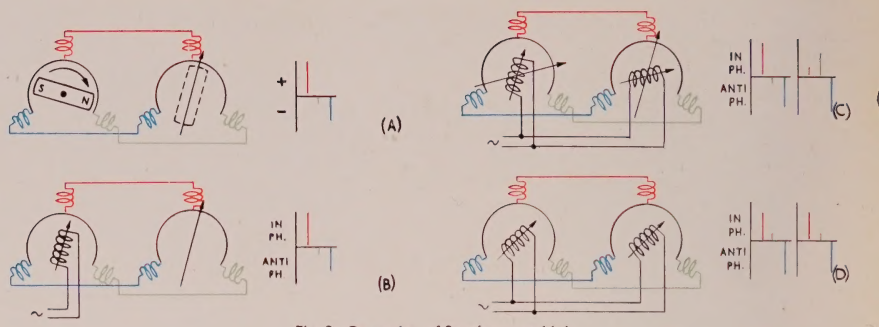

Fig. 3. Operation of Synchronous Link

negative it is now either in phase or anti-phase with the energizing voltage. The curves of Fig. 2 still apply but are now to be read according to the instructions at the *right-hand* side of the figure, the zero position lying on the vertical axis of Fig. 3(b), and the voltage diagram at the right of Fig. 3(b) shows alternating voltages.

If both stators have wound rotors and both are energized with a.c. each rotor field (shown by a short arrow) induces voltages in its stator and if the two rotors are in different positions, as in Fig. 3(c), then the stator voltages in corresponding windings are different, as shown in the voltage diagrams at the right of the figure. Difference currents flow between the stators so that each rotor sets up a corresponding field in the other stator (shown by a long arrow) and torques are exerted upon the rotors to bring them into coincident positions, shown in Fig. 3(d), when the voltages balance and there are no inter-stator currents and no torques upon the rotors. If one rotor is used as transmitter, and is moved, the other acts as receiver and follows. This is the basic a.c. data transmission system and in Magslip terminology is known as a synchronous link or Sy-L.

MAGSLIPS AS ALTERNATORS

Since the stator of the conventional Magslip is identical with that of an alternator it is only necessary to energize its rotor with d.c. in order to use the element for that purpose. There is, however, an important difference between the ordinary alternator and the Magslip in that the latter is an instrument of high precision; consequently the polyphase voltages derived from Magslips have good wave form, with low harmonic content and accurate displacement between phases subject, of course, to loading.

Clearly the wound rotor energized with d.c. may be replaced by a permanent magnet, and a three-phase Magslip alternator of this type is available under Muirhead type number E-28-C/1. A Magslip element having only two stator windings may, of course, be used as a two-phase alternator and such a machine, with a permanent magnet rotor, is available under Muirhead type number E-28-A/1.

VARIABLE-PHASE ALTERNATORS

If a Magslip element having a rotor with two windings at right-angles is used as an alternator it is possible to provide for electrical variation of the phase of the output with respect to the mechanical drive. Fig. 4(a) shows two potentiometers connected with a d.c. source represented by the battery. The junction of the rotor windings is connected to the junction of the potentiometers and the ends of the rotor windings are connected to the sliders. If the potentiometer sliders are ganged, as shown, and moved together, then the current in one rotor winding increases whilst that in the other falls. The resultant field is thus oriented and the full travel of the potentiometers covers one quadrant. If the polarity of the d.c. supply is reversed the opposite quadrant is covered. The circuit of Fig. 4(b) enables the remaining two quadrants to be covered. In this case the two sliders are to be moved in opposite directions in the figure. The type of element most suitable for this arrangement has two identical rotor windings, but such elements are uncommon.

A little consideration will show that, as the potentiometer sliders are ganged, the alternator voltage will vary to some extent over the range. This may be avoided by coupling the sliders through a suitable non-linear mechanism or by using potentiometers with graded resistance tracks.

Clearly the use of a Magslip element with two stator windings enables a two-phase supply of variable phase to be obtained.

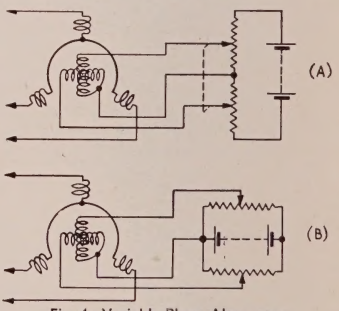

Fig. 4. Variable Phase Alternator

A.C. SUPPLIES OF VARIABLE PHASE

If a three-phase supply is connected to the stator windings of a Magslip element, as shown in Fig. 5, it will produce a uniform magnetic field rotating at supply frequency. If the element

has a rotor with a single winding then a single-phase alternating voltage may be derived from it. Turning the rotor alters the phase of the output voltage with respect to the supply so that the element provides a single-phase a.c. supply of infinitely variable phase. The purity of its output waveform depends on the waveform and phase-angle relationship between the phases of the three-phase energizing supply as well as on the load.

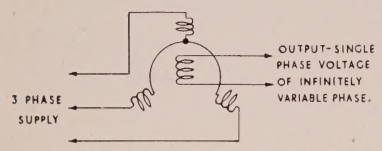

Fig. 5. A.C. Supply of Variable Phase

In the same way, if an element having two identical windings at right-angles on its rotor is employed, a two-phase voltage of variable phase is obtained and if a differential element having three windings on its rotor is used the output is in the form of a three-phase supply of variable phase.

By the use of a Magslip element having two stator windings at right-angles a rotating field is also produced and single-, two- or three-phase supplies of variable phase may be derived from a two-phase supply by using rotors having appropriate windings. Alternatively, if an element having two identical windings on its rotor is available, then two- or three-phase outputs may be obtained from the stator, according to its type, by connecting the two-phase supply to the rotor windings.

A.C. SUPPLIES OF VARIABLE FREQUENCY

If, in the arrangements just described, the phase is varied steadily and continuously in one direction then complete cycles will be lost or gained over a period of time. Hence, if the Magslip rotor is driven the output frequency is a function of supply frequency and rotor speed. For example, if a Magslip is energized from a 50 c/s supply and the rotor is driven at a speed of 600 rev./min. (i.e., 10 revolutions per second) in the direction in which the field rotates then the output frequency will be $50 - 10 = 40$ c/s. If the rotor is driven at the same speed in the opposite direction then the output frequency will be 60 c/s. The frequency is, of course, infinitely variable by varying the speed of revolution of the rotor. The output voltage varies with rotor speed.

As before, single-, two- or three-phase voltages may be obtained by employing Magslip elements whose rotors have one, two or three windings.

DIFFERENTIALS

In mechanical instrumentation and control devices the differential finds a large field of application because of its versatility. By its use it is possible to combine two input movements and to derive a third movement which is the sum or difference of the input movements or to vary the phase relationship of a driven member in relation to its drive. A detailed comparison with its Magslip counterpart is therefore of interest.

MECHANICAL DIFFERENTIAL

Fig. 6 shows a mechanical differential having shafts A, B and C, each carrying a bevel gear. A frame F, mounted for free rotation about shaft A, incorporates a further bevel gear meshing with that on shaft C. A gear D, meshing with those on shafts A and B, may rotate freely on a pin carried on frame F. The gears on shafts A and B, and gear D, all have the same number of teeth, whilst the gear carried on shaft C has half the number of teeth of the gear integral with frame F. Rotational direction arrows are shown on the three shafts.

Rotation of shafts A and B in the directions indicated produces rotation of shaft C, the relationship, expressed in degrees of angle or revolutions, being $A + B = C$. Rotation in the opposite direction may be expressed by changing signs, whilst if the input motions are applied to shafts A and C, or to shafts B and C, the formula may be appropriately transposed.

ELECTRICAL DIFFERENTIAL

The functions of the mechanical differential may be reproduced exactly by a Magslip system with the advantage that, whereas the separation of the devices connected to the mechanical differential is limited to a short distance, the Magslip elements may be widely separated

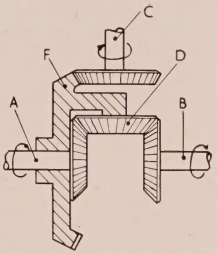

Fig. 6. Mechanical Differential

because the rotational data is transmitted by electric cables.

Fig. 7 shows a Magslip differential circuit, the central element with three windings on both stator and rotor being the differential element. There are two types of Magslip differential element, the hunter and the follow-through transmitter. Although they are fundamentally alike, the hunter has a lower impedance and is normally used as the output element where a certain amount of mechanical torque is required whilst the follow-through transmitter is more generally used where one of the input motions is applied to its rotor and the output is derived from one of the end elements, which may be a Magslip receiver (indicator), but is more usually a coincidence transmitter. The latter element is similar to a transmitter but its rotor winding has a higher impedance and is generally employed to feed an amplifier or other device having a high input impedance.

Referring to Fig. 7, which shows a hunter

system, the right-hand transmitter sets up a field in the differential stator as already described. In the same way, the left-hand transmitter produces a field in the rotor and a torque is exerted on the rotor to move it into the position in which the two field axes coincide. If a movement is applied to the right-hand transmitter the differential stator field is oriented and the rotor follows the field. If, on the other hand, a movement is applied to the left-hand transmitter, then the differential rotor field is oriented *with respect to the rotor* and the rotor is constrained to move to allow the two field axes to remain in alinement.

If a movement is applied to the transmitter on the left to cause the rotor field to turn

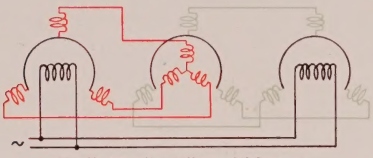

Fig. 7. Magslip Differential System

clockwise with respect to the rotor then the rotor will move anti-clockwise by that amount; if a second movement is applied to the transmitter on the right to turn the stator field anti-clockwise then the rotor will follow. The total movement of the rotor is thus the sum of the two transmitter movements. If the direction of movement of one transmitter is reversed then the rotor movement corresponds to the angular difference between the transmitter movements.

It will be clear that the spindles of the three elements of the Magslip differential system behave exactly like the shafts of the mechanical differential. Fig. 8 shows, in diagram form, the three elements of a Magslip differential system labelled A, B and C, B being the differential element. Directional rotation arrows are shown. In the normally-connected hunter system (that is, with terminals of like number connected together) the rotational relationship is A+B = C. As the follow-through transmitter is usually used in cases where the output is taken from an end element its internal electrical connections are, for convenience, altered so that the relationship is A + C = B.

In any electrical differential system the direction of rotation of either of the end elements

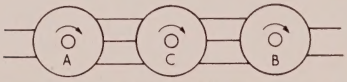

Fig. 8. Rotation Direction of Magslip Differential

may be reversed in relation to the others by reversing the connections in two of the stator lines. Thus, a two-pole changeover switch is equivalent to a reversing gearbox in the mechanical case and the switch may, moreover, be located at any convenient point.

As in the mechanical case, several differential elements may be arranged in cascade to provide for the 'mixing' of a number of inputs.

ELECTRO-MECHANICAL DIFFERENTIAL

By the use of the circuit shown in Fig. 9 a mechanical movement may be modified by electrical means so that the device functions as an electro-mechanical differential. An element having two rotor windings at right-angles is used and, here again, one having two identical windings is the most suitable.A potentiometer having four points of connection to its resistance track and two sliders at right-angles is arranged as shown. Turning the sliders varies the currents in the rotor windings, thus turning the rotor field electrically. The relationship between field rotation and potentiometer rotation is, however, not completely linear.

The arrangement could be applied to a transmitter which has its rotor mechanically connected to a controlling mechanism and in which it is desired that the controlled mechanism shall follow exactly but the datum point from which the controlled mechanism operates is to be variable. If it were desired that the controlled mechanism should be capable of operating from only two fixed datum positions then a simplified arrangement could be used, as shown in Fig. 10. In that arrangement the

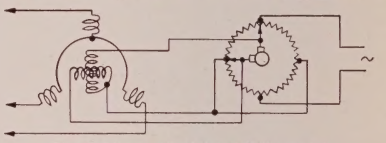

Fig. 9. Electro-Mechanical Differential

controlled mechanism will move strictly in accordance with the movement of the transmitter but the datum point from which it moves may be changed merely by throwing the switch from one position to the other. Variable resistances may be included to provide for initial adjustment of the two datum points.

Evidently, a number of variations of these arrangements is possible. A relationship between the circuit of Fig. 9 and those of

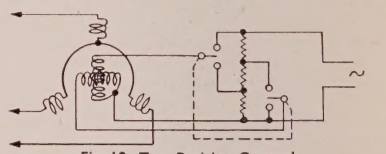

Fig. 10. Two-Position Control

Figs. 4(a) and 4(b) will also be seen. In fact, the circuits of Figs. 4(a) and 4(b) function as differential circuits in that they produce the same effect as a mechanical differential inserted in the drive to the alternator.

Where only a small differential movement is to be provided by electrical means — say less than 30° of rotation — this may be produced by applying a second voltage to the cross winding without altering the first voltage applied to the energizing winding, as shown in Figure 11. An X-Co transmitter (described below) is sometimes used for this purpose, the second voltage being applied to the high impedance winding.

COMBINED CO-T/SY-L SYSTEM

The Magslip X-Co transmitter has two windings on its rotor, but differs from those elements mentioned earlier in having one rotor winding of low impedance, suitable for connection to the energizing supply, and one winding of high impedance, similar to that of a coincidence transmitter. An interesting application of this element is shown in U.S. Patent No. 2429605 and is illustrated in Fig. 12.

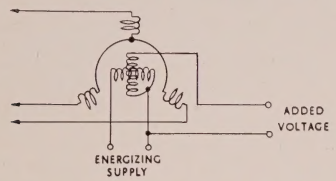

Fig. 11. Electro-Mechanical Differential with Limited Range

It is described in relation to aircraft instruments such as the Gyroscopic Artificial Horizon. The element on the left in the figure is an ordinary transmitter whilst that on the right is an X-Co transmitter. The transmitter rotor is coupled to a gyroscope which, when in operation, maintains its vertical datum attitude. One rotor winding of the X-Co transmitter — that having a high impedance — functions as a coincidence transmitter and feeds a servo

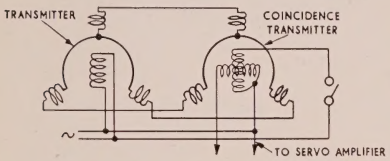

Fig. 12. Co-T/SY-L System

amplifier. In operation, any deviation of the aircraft from its proper attitude causes the gyroscope to turn the transmitter rotor and the other element delivers a signal to the amplifier. The amplifier output drives a motor which, in turn, operates a control surface to restore the aircraft to its proper position. Resetting is provided by coupling the control surface to the X-Co transmitter rotor. Before the gyroscope is started up it must be brought to its correct vertical position and this is done by locking the rotor of the X-Co transmitter element in the correct datum position and closing the switch which energizes its second rotor winding from the supply. The two elements then become a synchronous link, with the X-Co transmitter as transmitter and the torque developed in the receiving element (that on the left) turns the gyroscope into its correct position. The switch is then opened and the apparatus functions normally.

COMPARING THE RELATIVE PHASE OF TWO THREE-PHASE SUPPLIES

The adaptation of a Magslip type element to comparison of the relative phase of two three-phase supplies is described in U.S. Patent No. 1818787 (now expired), the arrangement being shown in Fig. 13. The element has a normal stator with three windings whilst the rotor consists of a simple soft iron or laminated structure carried on the spindle; each stator winding is connected to one line of each of the three-phase supplies through resistances of equal value and the connection of the three windings is such that one three-phase supply tends to produce a field rotating in a clockwise direction and the other three-phase supply tends to produce a field rotating in the anti-clockwise direction. The resultant field is an alternating field whose direction depends upon the phase relationship between the two three-phase supplies. The rotor alines itself with the axis of the field but, since it is unpolarized, it will be clear that it may take up either of two positions, 180° apart.

The application contemplated in the Patent Specification referred to is a synchroscope for synchronizing three-phase alternators prior to switching them on to a power supply network. If the frequencies of the two supplies are equal then the rotor remains stationary and its angular position indicates the phase relationship between the two supplies. If the frequency

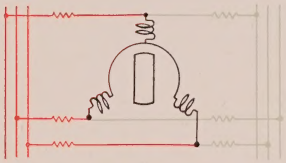

Fig. 13. Magslip Synchroscope

of one supply is higher that that of the other then the rotor rotates at a speed equal to half the difference in frequency. A suitable dial would carry a double calibration, each part occupying 180° of the scale, and a double ended pointer would be used.

The resistances shown in Fig. 13 prevent heavy short-circuit currents from flowing between the two three-phase lines. These resistances naturally entail a considerable wastage of power and a more efficient arrangement is shown in Fig. 14. In this arrangement the stator has two independent sets of windings. It will be understood that, although shown side by side in the figure, each pair of corresponding windings is co-axial. One set of windings is connected to each three-phase supply, the connections again being such that one set of windings produces a field rotating in the clockwise direction and the other set of windings produces a field rotating in the anti-

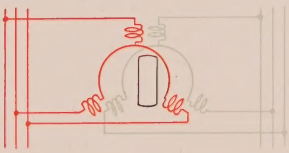

Fig. 14. The 'Monodiff'

clockwise direction. The resultant field is again an alternating field whose axis depends upon the phase relationship between the two three-phase supplies and a difference in frequency produces rotation of the rotor. This instrument is supplied as the 'Monodiff', Muirhead type number E-82-B/1.

One advantage of the instrument of Fig. 14 is that the three-phase supplies are isolated from each other. Furthermore, if the instrument is required to compare the phase relationship between two three-phase supplies of like frequency but of different voltages then the turns ratio between the two sets of windings may be altered to correspond. At the instant when the two rotating fields are in opposition, the currents in the stator windings reach a peak. In some applications it may be desirable to include resistances to limit the peak current.

It is obvious that the use of this instrument may be extended. For example, if a rotor having a single winding is introduced then a single-phase voltage will appear in this winding, having a magnitude dependent upon the relative angular positions of the field axis and the winding axis, being at maximum when the two are coincident and zero when the two are mutually at right-angles. By connecting this winding to the input of a servo amplifier of the usual type a servo mechanism may be provided which is responsive to the phase difference between two three-phase a.c. supplies.

If a rotor with three windings is employed a signal suitable for application to a Magslip stator is obtained and a receiver (indicator) may be connected to it. The receiver then indicates the phase difference and the 'Monodiff' rotor functions as an interposed differential which may be used to add or subtract a further quantity or for initial setting up to a zero position.

The 'Monodiff' may be employed to compare the phase relationship of any two quantities which can be represented by three-phase voltages. As an example of its application, it may be used for indicating the synchronism, or departure from synchronism, between the two engines of an aircraft. A Magslip three-phase alternator is driven by each engine and the outputs of the two machines are connected to the respective stator windings of the 'Monodiff'. The phase relationship between the engine shafts, or any difference in speed, is indicated by a pointer on the instrument spindle, in conjunction with a dial having a centre-zero marking.

INSTRUMENTS, ELECTRONICS & AUTOMATION EXHIBITION
OLYMPIA - LONDON - 7-17 MAY 1957

On Stand 901 we are exhibiting our newest instruments, and also the more important of those which have withstood the test of time. As contributing to the progress of AUTOMATION, one of the themes of this exhibition, we are showing our latest range of MIL Synchros: these are manufactured to U.S. MIL synchro installation drawings and tested to specification MIL-S-16892. Synchro Test Equipment is being demonstrated; this equipment has been developed for testing synchros to specification MIL-S-16892, and the design is such that it may be used for routine testing by unskilled personnel, yet to a laboratory standard of accuracy.

Three instruments, which are of great utility in their respective spheres, are worthy of mention, for when used in combination as a piece of test equipment, they constitute an effective transfer-function analyser for investigating network phase/amplitude response and the frequency response characteristics of servo systems and industrial process controls.

They are the D-729 L.F. Phasemeter which measures the phase and difference in level between two a.c. voltages presented to it over the frequency range 0·5 c/s to 10 kc/s; the D-788 Low-frequency Analyser which for this purpose is used to limit the effects of waveform distortion; and the D-638 Muirhead-Wigan Decade Oscillator — frequency range, 0·1 c/s to 2120 c/s — to provide a test voltage of the required frequency when this is required.

Examples of facsimile transmission equipment will be seen, including the D-770 Portable Picture Transmitter of 'attache-case' size, yet capable of transmitting photographs with the highest definition and tonal fidelity. Also, representative examples of Chart Transmitters and Recorders which have become the standard machines for weather map transmission in many meteorological organizations.

An outstanding demonstration of precision control is given by our latest Compensated Gyro Control Gear for ship stabilization which is responsive to four characteristics of motion and attitude of the ship under the influence of wave motion.

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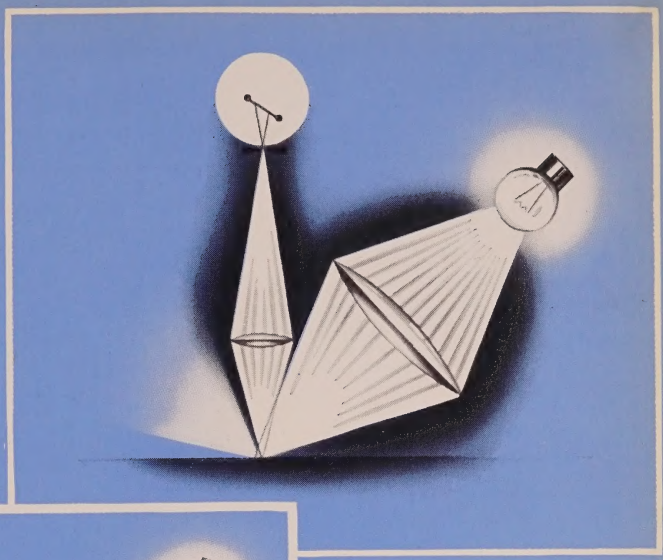

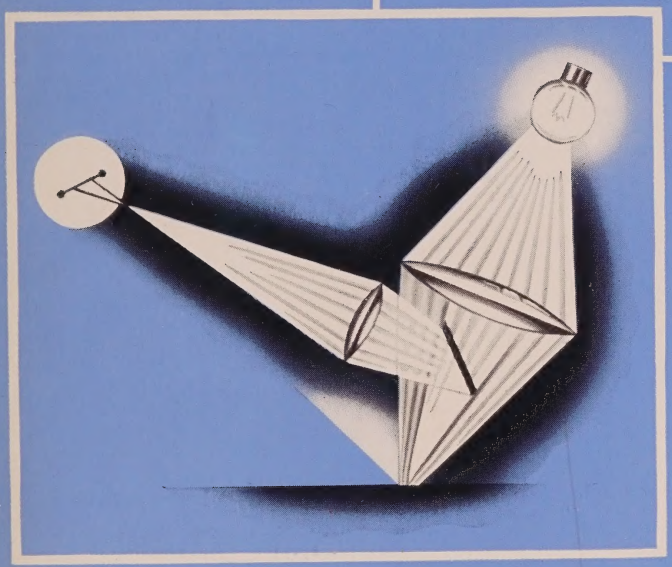

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THE FRONT COVER

The cover design is symbolical of an improved optical scanning system employed in many of our facsimile transmitters which is described elsewhere in this issue. It also symbolizes our constant endeavour to improve on designs that once we thought were the best — in fact, for us, the best is never good enough.

ERRATA — TECHNIQUE VOL. 11 NO. 2.
We regret the following errors in Technique, Vol. 11 No. 2
Page 2: Relevant literature, 6776-A should read 6736-A
Page 6: Column 1, line 33 — A, B and C, B being . . . . . should read: A, B and C, C being . . . .

MUIRHEAD SYNCHROS

We are pleased to announce the addition of the following items to our range of synchros:

15RS4 A size 15 400 c/s resolver
18CDX6a A size 18 60 c/s control differential transmitter
15CT6a A size 15 60 c/s control transformer
Servo Motor MK 14 MOD 2 A size 11 servo motor for 115 volts 400 c/s. This servo motor, together with servo motors MK 8 MOD 1 and MK 7 MOD 1, can also be supplied with low impedance control windings for use with transistorized amplifiers.

In accordance with Bu.Ord. policy, we have renumbered our size 11 control transmitter and control transformer 11CX4b and 11CT4b.

FEEDBACK RESOLVER

Users of the 3″ Magslip Resolver No. 2 (E-24-C/1) will be interested to learn that we now have a feedback resolver available in the 2″ Magslip size. This instrument is numbered E-64-C/1 and has the same accuracy as its 3″ counterpart.

THE D-695-A DECADE OSCILLATOR AND SOME APPLICATIONS

By A. Cooper, B.Sc. (Hons.) A.M.I.E.E.* and
S. N. Ray, M.Sc., B.Sc. (Eng.) M.I.E.E. F. Inst. P.†

OVER a period of years a number of types of Muirhead-Wigan Decade Oscillator have been produced. Their great popularity has been due largely to the precise frequency setting obtainable using the decade principle together with the ease and accuracy with which readings may be repeated. Between them a total frequency range of 0·1 c/s to 111 kc/s has been covered, but for certain applications such a wide frequency range is not necessary, and the D-695 Muirhead-Wigan Decade Oscillator, having a frequency range of 10 c/s to 30 kc/s, has been introduced to meet this need. Restriction of the frequency range has resulted in an instrument which is compact in size, simple to operate and relatively inexpensive.

FREQUENCY STABILITY AND ACCURACY

The reduced frequency range enables certain new features to be incorporated, one of which is the removal of the manually operated oscillator drive control, which was a feature of earlier types, yet maintaining a highly constant output level with varying frequency, even when a balanced and screened transformer is switched in for communication testing. Within five minutes of switching on, the frequency accuracy is ± 0·2% from 100 c/s upwards, and subsequent frequency stability is 0·02% or better per hour.

USE OF NEGATIVE FEED-BACK

An output level of 10mW into 600 or 10 000 ohms being considered adequate, considerable negative feed-back has been employed in both the drive and output stages, giving a total harmonic content of 0·2% from 30 c/s upwards. Such feed-back, together with a novel thermal device for controlling the drive level, renders unnecessary the usual closely controlled H.T. and heater supplies, with a consequent important reduction in size and weight. It also renders the performance almost completely independent of large changes in valve characteristics. The value of the feed-back can be judged by the fact that oscillators, having been adjusted precisely to 30 kc/s a few minutes after switching on from cold, remained constant within 3 c/s (0·01%) throughout a full working day. Full use can thus be made of the resetting accuracy of 1 c/s available at this frequency.

OUTPUT FACILITIES

The oscillator provides 600 ohms balanced and 600 ohms unbalanced output circuits and a 10 000 ohm unbalanced output circuit each being selected by means of a three position switch. Negative feed-back in the output stages produces in the two 600 ohms positions a low output impedance; about 50 ohms capacitive at 100 c/s reducing rapidly to 10 ohms as the frequency increases, thus rendering the output an almost constant voltage generator. The output level is constant within 0·1dB (1%) from 100 c/s to 10 kc/s and approximately within 1dB from 30 c/s to 30 kc/s. The 600 ohms balanced position affords a truly balanced-to-ground output via a transformer, the centre tap of which is brought out to a terminal; this makes the instrument very suitable for transmission measurements particularly as the output level is continuously monitored by a built-in bridge rectifier meter. The harmonic content and hum level at the output have been kept very low, being – 70dB on 10mW. Attenuation characteristics of filters, therefore, can be plotted without the need for a tuned detector.

For conditions where a balanced output is not essential, and minimum harmonics below 30 c/s, together with still greater constancy of output level are required, the 600 ohms unbalanced output is the most suitable to use. This is provided via a large capacitor, and the output impedance varies in a similar manner to that of the balanced case.

Finally, if maximum voltage across an impedance of 10 000 ohms or more is required then the 10k ohms unbalanced position should be used, when a maximum of about 12 volts is available, with 0·6 % harmonic distortion down to 10 c/s.

FREQUENCY RANGES

The basic frequency range is 10 to 3120 c/s. This can be multiplied by 10 by means of a key switch, and as no change in output level occurs when this is operated, rapid frequency changes can be made.

Frequency selection is by means of a three-position switch : THOUSANDS, marked 0, 1, 2, a HUNDREDS decade switch, marked 0 to 10, TENS decade switch, marked 1 to 10, and a continuously variable UNITS control, engraved with individually calibrated 1 c/s steps which are

* Muirhead and Company Limited.
†Senior Lecturer, Borough Polytechnic, London.

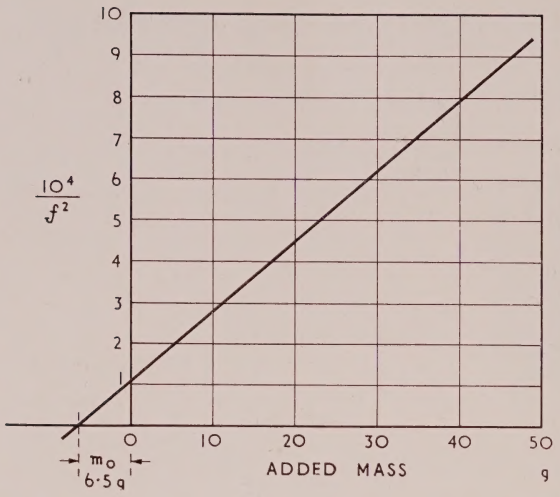

Fig. 1

sub-divided into fifths. A resetting accuracy of 0·1 c/s is thus obtainable on the ×1 range, or 1 c/s on the ×10 range.

It is therefore possible to reset to at least 0·1% above 100 c/s, and in general this figure is justified by the absolute accuracy of 0·1% obtainable between 100 c/s and 10 000 c/s.

APPLICATIONS

Considerable use can be made of the fact that the output level is very constant with frequency and time. In the checking of low range a.c. voltmeters, at frequencies other than the supply frequency, this feature has proved invaluable.

Its ease of operation appeals to production engineers, to communications engineers, and to technical colleges, both from the points of view of frequency selection, and of rapid stabilization of frequency and amplitude.

By using the continuously variable control as a very fine frequency adjustment against a frequency standard of 0·01% accuracy it is possible to interpolate over a restricted range to much greater accuracy than the ±0·2% claimed, owing to the use of precision wire wound resistors in the decade switches.

It should be noted also that this continuously variable control covers 10 c/s on the ×1 range, and 100 c/s on the ×10 range, and may thus be used to explore closely and accurately regions of particular interest such as those containing a resonance. In some such instances it may be worthwhile to drive this control mechanically to provide a frequency sweep.

ELECTRO-ACOUSTIC MEASUREMENTS

For many laboratory demonstrations and measurements the output of the oscillator is quite adequate and at the Borough Polytechnic, London, routine electro-acoustic experiments have been devised which exploit some of its features. These include the high resetting accuracy of 0·2 c/s at low audio frequencies, and the constancy of output with change of frequency. Two such experiments are described below.

DETERMINATION OF THE CONSTANTS OF A VIBRATING SYSTEM

This experiment is analogous to the measurement of inductance and capacitance in an electrical tuned circuit by a resonating method. The stiffness (S) represents the reciprocal of capacitance (elastance) and is kept constant, whilst the mass (M) representing inductance, is varied by adding known weights to the system.

A Goodman electro-mechanical vibrator of low impedance is driven through a suitable matching transformer, and its resonant frequency found by varying the oscillator frequency so as to obtain maximum current in the vibrator coil. Known masses are then added in turn to the vibrator piston and a new resonant frequency determined for each addition.

A plot is then made of values proportional to $1/f^2$ against added mass as in Fig. 1, and a straight line drawn through the points gives the mass (m_0) of the vibrating system above as the intercept on the negative side of the abscissa (mass line). Also the slope of the line gives the stiffness in accordance with the relationship:

$4\pi^2 f^2 = S/(m + m_0)$

where m is the added mass.

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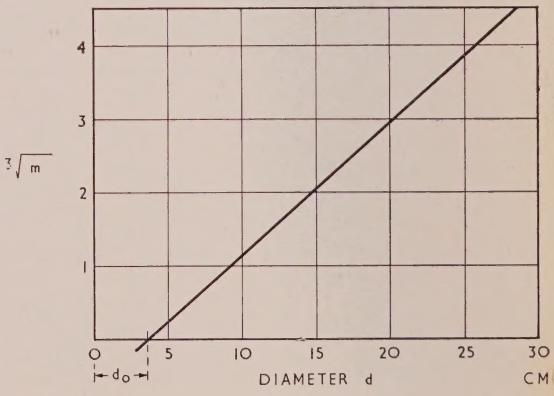
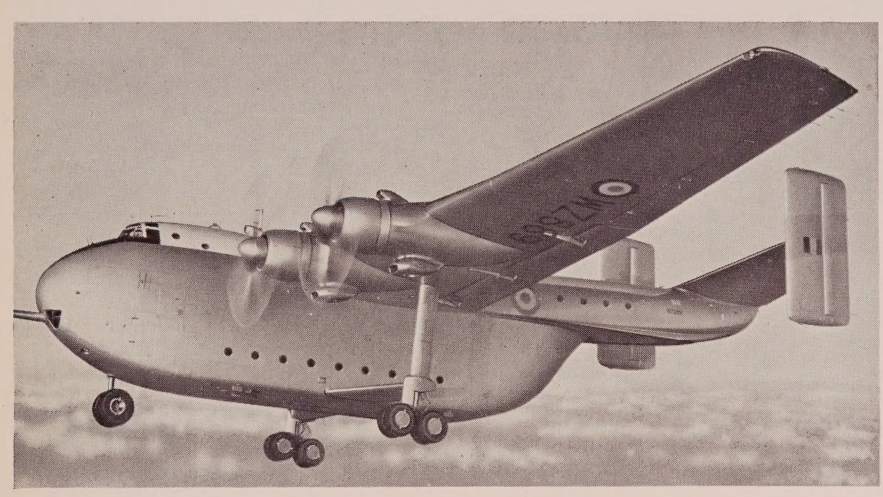


Fig. 2

NOISE MEASUREMENTS IN THE AIRCRAFT INDUSTRY

A description of measurements made at the Blackburn and General Aircraft Ltd., BROUGH, England, using the Muirhead-Pametrada Wave Analyser

by H. FUCHS, B.Sc., Ph.D.* and R. HOODLESS, A.M.I.E.E.*



NOISE MEASUREMENTS IN THE 'BEVERLEY'

In order to minimize the noise in the crew's quarters of the Beverley 'C' Mk. I aircraft, an investigation of the frequency spectrum of the noise was required in order to decide the most effective type of soundproofing to employ.

During flight, magnetic tape recordings of the noise at various points in the aircraft were made simultaneously with an absolute sound intensity measurement at each point. After flight, the tape was made into endless loops and played back through a Muirhead-Pametrada Wave Analyser, set to 1/3 octave scan. A graph of proportional noise content *v.* frequency was thus obtained, and by referring to the measured intensity at the time of recording, the proportional scale was redrawn to give absolute intensities.

Typical records of 1/3 octave intensities before and after soundproofing are shown in Fig. 2. Fig. 1 shows these intensities re-calculated and drawn on a full octave scale in order to compare the Beverley 'C' Mk. I results with the North American Harvard Mk. IV and the Fairchild C-119-F 'Boxcar'.

It will be seen that at those frequencies most disturbing to the human ear, i.e. 1000-4000 c/s. a reduction of approximately 20dB has been achieved.

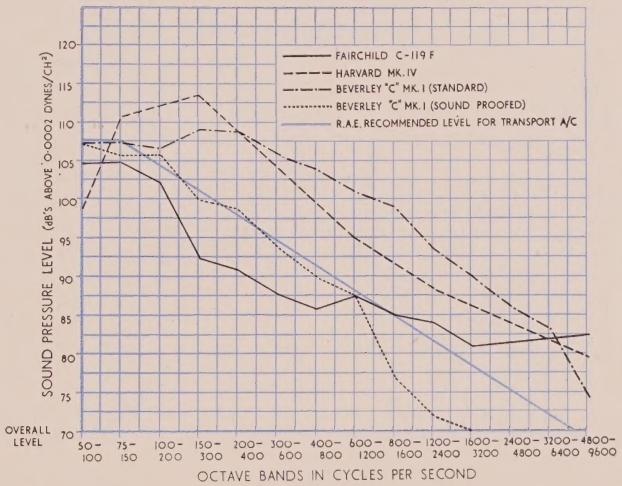


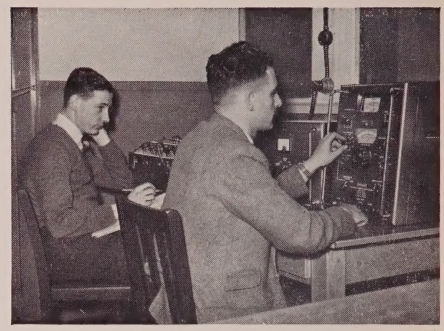
Fig. 1

*Blackburn and General Aircraft Ltd

TESTS ON THE TURBOMÉCA GAS TURBINE-NOISE MEASUREMENTS

It is the company's intention to produce the Turboméca range of engines for industrial as well as aeronautical purposes, and as an industrial installation, a high degree of sound-proofing is required. Consequently, a programme of noise measurements is being carried out to determine the most economical way in which the soundproofing can be carried out.

As it is essential to know the order of frequency of the main sources of noise before suitable sound insulation systems can be produced, measurements are made, using a calibrated microphone and a Pametrada Wave Analyser switched to the 1/3 octave position. By producing curves of the main frequency components, and their polar distribution at various engine speeds, it is possible to design an economic sound-proofing installation to bring noise intensities down to those limits set by industrial users.



Tape recordings of noise measurement being 'played back' to the Analyser.

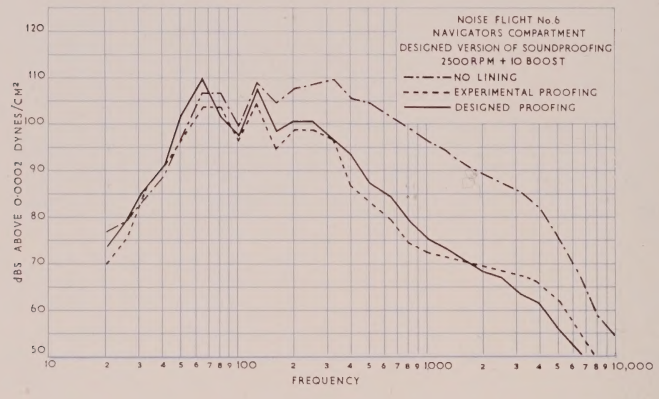


Fig. 2

VIBRATION MEASUREMENTS

If in a similar manner vibration measurements are made with the Wave Analyser switched to 'in tune — high selectivity', it is often possible to identify a particular mode of vibration with some component within the engine. Although it is possible to produce these vibrations in the laboratory, it is better to carry out these measurements with the engine in operation, since their frequencies are often modified by the effects of temperature, centrifugal force and air loads when actually working in the engine, and the laboratory figures are not necessarily accurate enough to be used in proposed component modifications.

Noise measurements in the 'Beverley' being made and recorded during flight.

MISCELLANEOUS USES OF THE WAVE ANALYSER

In the laboratory, the wave analyser has numerous applications, which, although not sensational in themselves, avoid the necessity of producing a complex and often costly piece of equipment for a particular purpose.

Three such examples of this in use by Blackburn and General Aircraft are as follows:

(*a*) To 'clean up' a distorted waveform where the harmonic content is to be kept to a minimum.

(*b*) The measurement of a small, high frequency voltage in the presence of a comparatively large low frequency component.

(*c*) A variable width 'pass band' filter capable of being centred on various frequencies.

AN IMPROVED OPTICAL SCANNING HEAD FOR FACSIMILE TRANSMITTERS

by M. S. Pembroke*

THE establishment of picture telegraphy as a medium for the transmission and reception of graphic material is evidenced by widening applications which often create new problems.

A particular difficulty has been to obtain faithful reproduction of message originals possessing bulges and fold marks, or of documents carrying seals, labels, or tapes which present more than one information surface to be correctly interpreted by the scanning device.

Before considering this problem in greater detail a general method of optical scanning is described briefly, as follows:

The message form is placed around the transmitter message drum which is capable of simultaneous rotation and traverse, and a small fixed light spot is focussed on the surface to be scanned. Light picked up from an elemental area of the illuminated spot is converted into electrical energy by means of a photo-electric cell, and the signals so obtained are used to modulate a carrier frequency for the communication circuit.

Considering the arrangement necessary for scanning, the conventional pattern has the axes of its light producing and light collecting paths at an angle to each other so that directly reflected light from the surface being scanned cannot enter the collecting cone, see Figure 1. A disadvantage of this arrangement is that departure from the ideal case of a constant objective distance due for example to drum eccentricity causes relative transverse motion between the illuminated area and the point being viewed, and because the light intensity and the colour content of the illuminated area are not uniform, variations in the objective distance may produce different electrical signals for scanned tones of similar density. The optics are usually adjusted so that maximum output is obtained from the photo-cell; any variation of position of the light spot therefore gives a lower output and will cause a darkening of tones in the reproduction.

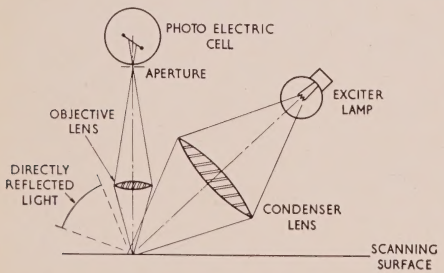


Fig. 1 Conventional optics: axes of light source and light collecting paths forming an angle at the scanning surface.

If the illumination at the surface to be scanned could be made monochromatic and also of uniform intensity over a sufficiently large area the arrangement of Figure 1 would be capable of handling all the message form imperfections likely to be encountered, but though simple in conception these conditions are not simply achieved. Attempts at a reasonable compromise for example by a measure of defocussing have shown promise of improvement but the overall light efficiency of the scanning head has been seriously impaired.

Whilst closely controlled manufacture practically removes machine errors that may vary the objective distance during rotation and traverse of the transmitter message drum, this cannot take care of the carelessly loaded or mechanically imperfect message form, and for this reason Muirhead transmitters are now fitted with recently designed scanning heads based on the principle described below.

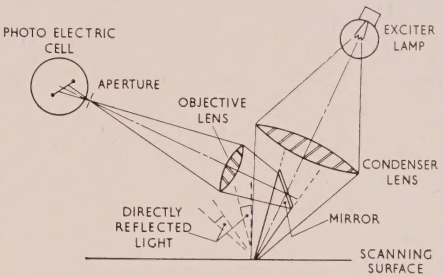


Fig. 2 Improved optics: no angular displacement between light producing and light collecting paths.

The design adopted and shown schematically in Figure 2 eliminates the angular displacement between the light producing and light collecting paths thus preventing relative motion between the illuminated area at the scanning surface and the viewing point. There will of course be out of focus effects with variation of the objective distance, but over what is considered to be a reasonable working range these are of small consequence only. In this respect, where maximum resolving power is required as in the case of high definition photo-telegraphy, care has been taken to ensure adequate focal depth of the objective lens and it is to this end that the inner cone has been chosen for the objective path.

It is necessary for the axis of the illuminating path to be inclined rather than normal to the scanning surface as indicated in Figure 2, otherwise, without taking special precautions small undulations at the scanning surface tending to produce an angle other than 90° would cause surface reflected light to enter the

*Formerly with Muirhead and Company Limited.

objective cone. The system is in fact quite tolerant to such irregularities as may be seen from the reflected light paths shown in Figure 2.

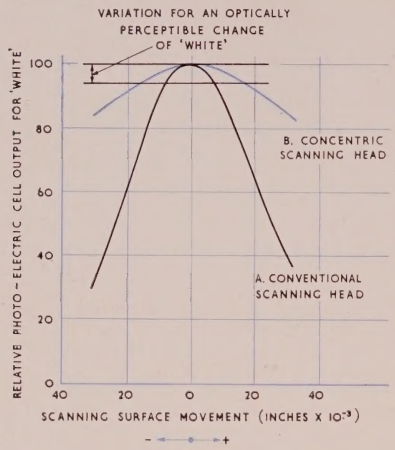


Fig. 3

For the purpose of comparison two curves of performance are shown in Figure 3. 'A' refers to the arrangement of Figure 1 and 'B' to a particular form of the concentric system fitted on a Weatherfax transmitter (Type D-658). It may be taken that a reduction of 10% in the 'white' photo-electric cell current will not produce a significant change of tone at a facsimile recorder, and for the case quoted it is clear that the D-658 transmitter fitted with a concentric optical scanning head has more than twice the tolerance to scanning surface imperfections than that attainable with previous arrangements. Figure 4 illustrates the meaning of Figure 3 in a practical form by comparing facsimile recordings made employing the two types of scanning head described, with the message form packed away from the message drum by 0·016 in., all other conditions being similarly maintained.

The advantage of the new arrangement which is the subject of a patent application is clearly manifest and its fitment to Muirhead transmitters will do much to improve reproductions which have been unacceptable when using the earlier method.

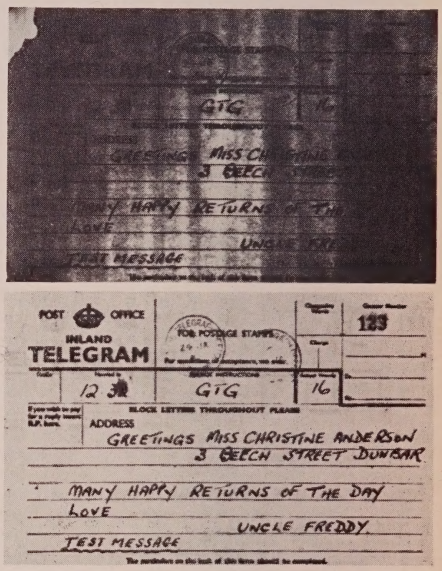


Fig. 4 Received copy of an original message raised 0·016 in. from the surface of the transmitter drum:
above: using conventional optics.
below: using improved optics.

continued from page 20

Where small changes of 0·2 c/s can be read accurately a rapid evaluation of m_0 can be made from two measurements:

1. The frequency of resonance f when the mass is m_0 only, and
2. The frequency $(f-\delta f)$ with an added mass m.

then $\delta f/f = m/2m_0$.

From Fig. 1 it will be seen that the frequency range used is 100 to 30 c/s. The vibrator mass in the particular experimental figures given can be read from the graph as 6·5 gm and the stiffness calculated as $2{\cdot}45 \times 10^6$ dynes/cm.

DETERMINATION OF THE ACCESSION OF INERTIA OF A VIBRATING DISK[1]

The accession or increase in the inertia (mass) of a vibrating disk arises from the resistance offered to the motion by the surrounding fluid. If light disks are attached to the vibrator piston the accession due to the increase in area of the piston can be determined, also the accession of the piston itself.

Three disks of different diameters are used with the vibrator of the first experiments. The frequency of resonance of the vibrator is found as each disk is added in turn. Then the apparent added mass of the disk can be read off Fig. 1 extrapolated and so the accession of inertia obtained. Typical figures are given below.

Diameter of disk	26·7	12·7	7·6 cm.
Added mass	69	3·5	0·4 g.

By plotting the cube root of m (added mass) against d (diameter of disk), as in Fig. 2, a straight line with intercept on the d axis is obtained, showing that the apparent mass (m) varies as $(d-d_0)^3$, where d_0 represents the effective diameter of an area screened by the body of the vibrator.

[1] *Theory of Sound (Vol 2), Lord Rayleigh*

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Publication 9751. D-729-B L. F. Phasemeter.

THE FRONT COVER

The D-649-G/AS illustrated on the cover is the latest in a series of D-649 Mufax 18in. Chart Recorders. The performance is basically similar to the D-649-G/A (automatic) machine but the degree of automaticity has been extended to include speed selection of the three helix speeds — 60, 90 and 120 rev/min. The speed selector circuit receives incoming phasing signals occurring once per revolution of the transmitter drum and compares the time interval between the phasing pulses with internally generated standard time intervals.
Depending on the repetition rate of the phasing pulses, and hence the transmitter drum speed, the speed selector circuit determines the operation of two relays which in turn control the mechanism which selects the corresponding helix speed.

NEW MUIRHEAD SYNCHROS

The range of Muirhead MIL Synchros and Servomotors in current production has been extended by the addition of the following new types.

SIZE 08	26V08CX4(B), 26V08CT4(B)
SIZE 11	11CDX4a, 11TR4a, 11TX4a, 11RS4, 11 Linvar, 26V11CX4a, 26V11CT4b, 26V11CDX4a, 26V11TR4a, 26V11TX4a
SIZE 15	15TR4b, 15TX4b, 15TDX4a, 15TDR4a
SIZE 18	18TR4a, 18TX4a, 18TDX4a, 18TDR4a 18CX6a, 18CT6a, 18TR6a, 18TX6a
SERVOMOTORS	MK 12 MOD 0, MK 16 MOD 0
TACHOGENERATOR	MK 1 MOD 1

A list of the full range of Muirhead Synchros can be had on request.
Designers requiring types not listed are cordially invited to discuss their requirements with our engineers who are accustomed to developing new types at short notice.
Reference Synchros: Limited quantities of the following types of Synchro are available having a superior accuracy. These Synchros are supplied with a full Certificate of Test and are intended for use as reference instruments for testing out new systems, etc.

11CX4b Max error 5′
11CT4b Max error 5′
15CX4a Max error 6′
15CT4a Max error 5′
15CDX4a Max error 6′
18CX4a Max error 4′
18CT4a Max error 4′
18CDX4a Max error 4′

THE ANALYSIS OF MUSCLE POTENTIALS BY MEANS OF A MUIRHEAD-PAMETRADA WAVE ANALYSER

by

A. NIGHTINGALE, M.A., F.Inst.P.*

MUSCLE POTENTIALS

Experiments and speculations upon 'animal electricity' are as old as the study of electricity itself. As early as 1720, Newton suggested that some 'subtle spirit' might be responsible for the forces between electric bodies and, by its vibrations, for the conveyance of messages along the nerves to the brain and from the brain to the muscles. The earliest demonstration of the production of electrical potentials by an intact human body was made by Hermann in 1877, and it is now known that both the motor nerves and the muscle fibres of active muscles produce electrical pulses known as action potentials. These can be detected by small metal disks placed on the skin over the muscle, or by needles inserted into the muscle. They may then be amplified and displayed upon the screen of a cathode ray tube in the form of a graph of p.d. against time (Fig. 1).

This picture is known as an 'electromyogram', and the apparatus employed is called an 'electromyograph'.

Electromyography is useful in the analysis of posture or movement in human subjects because of its great sensitivity; a very slight degree of contraction in the muscle is associated with relatively large fluctuations of potential. The method is being used at this Medical School to study the relative contributions of the leg muscles to the maintenance of the standing position. One interesting result was the discovery that the thigh muscles do not usually produce action potentials in this position, although they feel quite hard and might be expected to be active.[1] Apparently the knee is capable of 'locking' mechanically without muscular aid over a limited range. If the subject sways forwards or backwards from the comfortable standing position, the back and front thigh muscles (respectively) are eventually brought into action to prevent falling.

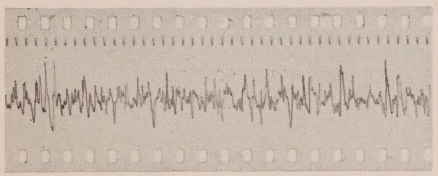

Fig. 1 Electromyogram taken from the biceps of a man holding a 2Kg weight in his hand (upper arm vertical, forearm horizontal).

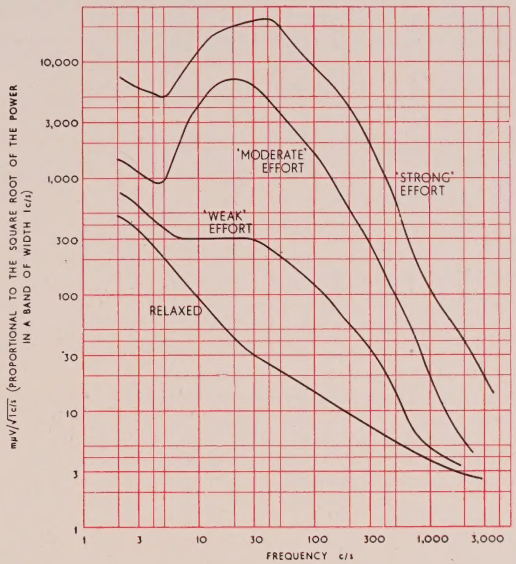

Fig. 2 Spectra of electromyograms taken from a thigh muscle of a man.

THE SPECTRUM OF THE ELECTROMYOGRAM

When a muscle contracts, the pulses from thousands of different fibres firing at random fuse together to produce a complex waveform of no definite frequency (Fig. 1). In designing an electromyograph amplifier the first problem is clearly the frequency band to be covered. The Muirhead-Pametrada wave analyser with its associated low frequency modulator, which together cover a frequency range from 2 c/s to 20 kc/s, has proved to be a convenient instrument for the purpose of providing this information. Fig. 2 shows the spectra of the electromyograms obtained from a thigh muscle of a man as he makes a weak, moderate or strong effort to contract his muscle, and also when his muscle is relaxed. The most important components associated with the contraction lie be-

*Physics Department, Guy's Hospital Medical School, London

tween about 10 c/s and 600 c/s. The components below 10 c/s are attributable to sources other than the nerve and muscle fibres. It should be emphasized here that in this work we were interested in the complex waveform detected by surface electrodes. Individual action potential pulses can be picked up by needle electrodes and the detailed form of each pulse is used in clinical electromyography to help in the diagnosis of muscle and nerve lesions. For this purpose a much higher range of frequencies is required; from about 50 c/s to 5 kc/s.

AMPLIFIER NOISE

The ultimate sensitivity of any amplifier is set by the noise generated in the amplifying circuit itself, and this becomes important in electromyography, and of course in electroencephalography and biological amplifiers in general, where the amplitude of the signal may be only a few microvolts. The wave analyser has been used to obtain the noise spectrum (Fig. 3). The dominant source of noise is flicker noise arising in the cathode surface. This can be identified since it is known to follow approximately the well-known $\frac{1}{f}$ law, which states that the flicker noise power per unit bandwidth is $\propto \frac{1}{\text{frequency.}}$ On the diagram of Fig. 3 the noise is expressed in terms of its r.m.s. voltage per $\sqrt{\text{unit}}$ bandwidth (referred to the input terminals), and it can be seen that at low frequencies the curve approximately follows the relationship $\frac{\text{r.m.s. value}}{\sqrt{1\ \text{c/s}}} \propto \frac{1}{\sqrt{f.}}$ At higher frequencies the curve flattens out as the anode shot noise becomes predominant. With the aid of the analyser it has been possible to reduce the flicker noise level by selection of valve type, selection of individual valves and adjustment of the operating conditions.

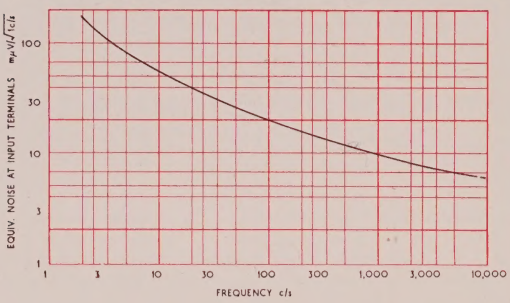

Fig. 3 Spectrum of amplifier noise.

METHOD OF USING THE ANALYSER

For frequencies above 20 c/s the analyser was used in the 'narrow band' condition, giving a bandwidth equal to about 4·5% of the centre frequency. This provides adequate selectivity for the types of spectrum shown in Figs. 2 and 3. In all measurements of random waveforms it is of course desirable to use as wide a band as possible consistent with the required degree of selectivity, since the fluctuations in the output of the selective circuit become more severe the narrower the absolute bandwidth. This is illustrated in Fig. 4, which shows that the average frequency of the envelope fluctuation of narrow band noise is roughly equal to the bandwidth. The analyser meter contains an electrical time constant of about 0·5 second, so that it gives a fairly smooth reading when the bandwidth is more than a few cycles per second. At low frequencies, however, the meter pointer fluctuates over a wide range. Now one could of course lengthen the time constant of the meter circuit, but this gives rise to difficulties, the most important being that a short burst of interference may go unnoticed and become included in the apparent mean value read by the meter. The author has therefore found it more convenient to use the meter with the time constant already provided, and to take a series of spot readings of the meter at intervals of a few seconds. The mean of the spot readings gives the required value, and the standard deviation can be calculated so that the number of readings needed to give a required accuracy can be estimated. For example, in the case where the bandwidth is 4·5% of the centre frequency, to obtain a standard error of the mean of 4%, it is necessary to take 40 readings at 20 c/s, 30 at 60 c/s, 10 at 190 c/s, 3 at 510 c/s and only one above 1000 c/s.

At frequencies below 20 c/s the low frequency modulator was used. The modulator causes the noise to modulate a carrier at 50 c/s, and the upper side band is selected by the analyser in its most selective condition. For example, to obtain a measurement at 2 c/s (the lowest frequency possible with this system), the analyser is tuned to 52 c/s. The bandwidth is then fixed by the analyser and is about 1 c/s. This is not as narrow as might be desirable for a band centred at 2 c/s, but considering the difficulty, discussed above, of making accurate measurements with a very narrow band it does represent a useful practical compromise.

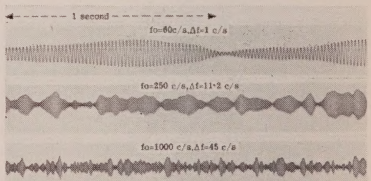

Fig. 4 Random noise waveforms showing approximate equality of envelope fluctuations and bandwidth.

The continuously variable frequency scale of the analyser and the precision with which a given centre frequency may be set, are valuable features in this type of work. For example, it is

(continued on page 32)

THE D-729 PHASEMETER AND SOME APPLICATIONS

by A. Cooper, B.Sc. (Hons.), A.M.I.E.E.*

Among the many different methods of measuring phase, that of making the reference and test signals equal and then adding them vectorially has proved very popular. It has so many advantages that its adoption in the D-729-A and B Phasemeters was an obvious choice, and subsequent experience has shown this decision to be a wise one. In the information which follows, the advantages will be outlined, and some of the resulting applications will be described.

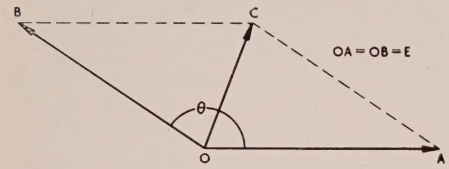

Fig. 1

PRINCIPLES OF MEASUREMENT

In Fig. 1 let OA represent the reference voltage and OB the test voltage, both of sinusoidal waveform, and let θ be the angle between. Suppose OB is adjusted to equal OA in magnitude; then it can be shown quite simply that:

OC = resultant vector sum of OA and OB
$= 2\ OA \cos \theta/2$.

Suppose further that OA is kept constant at value E. Then we have:

$OC = 2E \cos \theta/2$.

A voltmeter arranged to read OC will have a scale proportional to a cosine function. For an approximately linear scale the angle $\theta/2$ should be between 45° and 90°, or 135° and 90°. Thus θ should be between 90° and 270°. This can always be arranged by reversing the phase of OA, the reference vector, when θ is between 0° and 90°, or 270° and 360°. Because there are four equal values of the cosine in the range 0° to 360°, the voltmeter will have a single scale but four sets of figures: 0° to 90°, 180° to 90°, 180° to 270°, and 360° to 270°. In view of these four ranges there will be ambiguity of meter reading. This is removed firstly by the phase reverser, or 'sign changer' which tells whether the angle is in the first or fourth quadrant or alternatively in the second or third; and secondly by a phase retard network which is switched in to vary the phase of each signal in turn and will change the meter reading accordingly. This change determines which of the two remaining quadrants is the correct one.

Finally, since $\theta/2$ lies between 45° and 90°, then $\cos \theta/2$ lies between $1/\sqrt{2}$ and 0; OC, therefore varies between $E\sqrt{2}$ and O. Full scale reading on the voltmeter is made $E\sqrt{2}$ and the two signals can each be adjusted in turn to E on the meter before summing.

CIRCUIT DESCRIPTION

Referring to Fig. 2, the D-729-B Phasemeter will be described and any differences in the A model mentioned. The two voltages under test are applied to the phasemeter via the Channel 1 and 2 input co-axial sockets and from these are fed into identical buffer stages whose outputs are adjusted by COARSE (step) and FINE (continuously variable) controls. The outputs from the two buffer stages are connected to the PHASE RETARD switch which is in two halves, one for each channel, separated by an electrostatic screen. The Channel 1 output from the PHASE RETARD switch is fed via the QUADRANT control switch directly to the CIRCUIT SELECTOR switch, or to the SIGN CHANGER stage in which it is reversed in phase. An 'adder' stage follows the CIRCUIT SELECTOR switch and, depending on the position of the switch, the voltages may be applied to the stage separately in the CHANNEL 1 or 2 position, or together in the READ PHASE ANGLE position. The signal from the 'adder' stage is amplified and then taken via the INTERNAL AMPLIFIER switch to the meter circuit. An external selective amplifier may be connected between the OUTPUT socket and the METER INPUT socket, enabling particular frequencies

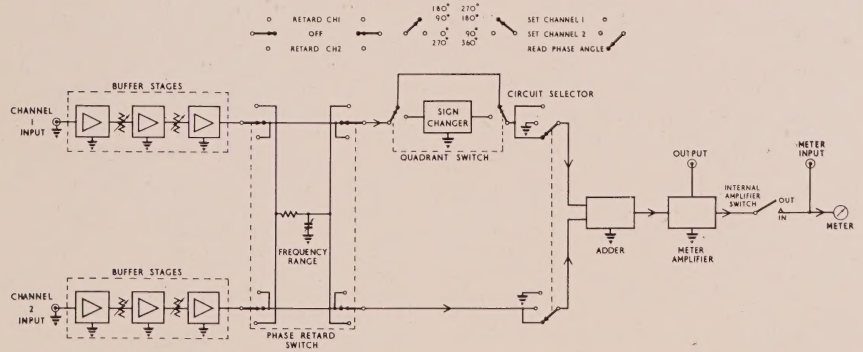

Fig. 2 Functional diagram D-729-B Low frequency Phasemeter

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of a complex waveform to be selected for measurement and indicated on the meter in the normal manner. This will be dealt with in more detail later. The impedance at each channel input socket is approximately 30 megohms in parallel with 15 pF. For measurements some distance from the instrument, low capicitance screened leads about two feet long are provided complete with 1 : 1 probes, or to special order, type D-850 10 : 1 attenuation probes, may be supplied. The capacitance at the input end of the 1 : 1 probes is 60 pF and the impedance of the 10 : 1 probes is 10 pF in parallel with 1 megohm. The latter enable voltages up to 200V to be applied.

METHODS OF USE

1. As a Transfer Function Meter and Voltmeter

The transfer function of a system may be determined by measuring the amplitude ratio of the input to the output, and the phase difference, using the two channels. By setting the continuously variable fine attenuators to zero and adjusting the coarse attenuators to give suitable output meter readings, the actual channel input voltages can be read, two voltage scales of 0–6 and 0–20, volts or millivolts, being provided on the meter scale. The coarse attenuator settings are marked in voltage as well as in decibels. Maximum full-scale sensitivity is 6mV and the accuracy in voltage claimed is ±5% over most of the range. A glance at Fig. 3, which shows the overall frequency responses of the A and B models, will immediately make clear that in the case of the model A, the response is within ±2% from 10 c/s to 50 kc/s, and in model B from 4 c/s to 10 kc/s. As an a.c. voltmeter with a high input impedance of 30 megohms and 15 pF at the coaxial sockets, the instrument possesses a great advantage over other types of phasemeter which measure phase only, or phase and amplitude difference. The voltage sensitivity is higher than many low frequency voltmeters, whilst the use of a high degree of negative feedback in all amplifier stages results in great stability with time and supply voltage variations.

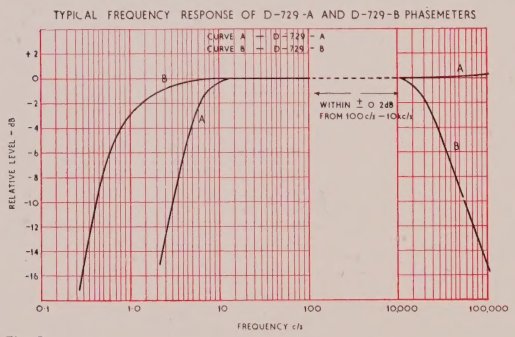

Fig. 3

2. Scale Expansion

It should be noted that a requirement of the method is that the two channels, with their buffer amplifiers, attenuators and sign-changer, should have the same phase-shift at all frequencies. This requirement has been met quite easily by using cathode-followers and anode-followers with substantially unit voltage gain; the two signals are thus summed at the low level of a few millivolts. Considerable voltage amplification is reserved for the resultant signal only, and phase-shift in this part of the circuit does not affect the result. This again contrasts favourably with methods requiring summing at high voltage or power level, such as those of the wattmeter and the limiter. An exceedingly important consequence of this comparison at low-level is the ability to scale-expand up to 300 times (50 dB) for certain phase-angles and input levels, before overloading any part of the circuit.

When measuring phase in the region of 0° or 180°, the meter indication is near zero. By decreasing the coarse attenuators by the same number of 10 dB steps, the meter indication can be increased until it reads beyond 30% of full-scale deflexion. This, of course, requires that the two input levels shall be above the minimum of five millivolts by the scale-expansion factor. For example, if the signals are both at least 300×5 millivolts, or 1·5 volts, then scale expansion by a factor of 300 is possible, and results in 0·2 degrees for full-scale deflexion. Now 0·2 degrees is only twelve minutes, hence it is possible to read down to about 2% of this value, which is 0·2 minutes or 12 seconds.

At first sight, two complications limit the usefulness of this facility, but both of them, under certain conditions, can be dealt with. The first concerns the equality of the two levels when being summed in the 'adder' stage. The more the expansion, the more nearly equal the two levels must be adjusted in order that the meter should indicate phase-angle and not level difference. It is sufficient to do this by adjusting the fine attenuator of one channel or the other by the small amount of not more than 0·2 dB (2%) in order to reduce the meter reading to a minimum. Over quite a wide frequency range it will be found that it is possible to scale expand the full 50 dB, whilst some scale expansion is possible any where within the 1° limit of the instrument.

The second is more serious; it is the presence of distortion in either or both of the waveforms. Working near zero reading implies that the fundamentals of the signals are almost cancelled out in the 'adder'. If harmonics and noise are not simultaneously reduced by the same factor, the meter reading may be entirely false. Fortunately, the use of a selective amplifier to make this effect negligible is not always necessary. A practical example of this occurs in the measurement of the power factor (loss angle) of capacitors (see page 31).

3. Use with Distorted Waveforms

Since harmonics in the two channels may not always be cancelled out, or may be present in only one channel, the use of a selective amplifier may be necessary in certain cases. Examination of the waveform on an oscilloscope or pen-recorder will indicate this.

A selective amplifier such as the D-669 (30 c/s –30 kc/s) or D-788 (3 c/s–3 kc/s) Frequency Analyser may be used in place of the internal flat amplifier by plugging it into the phasemeter circuit. The input of the tuned amplifier should be connected to the OUTPUT socket of the instrument, and the output to the METER INPUT socket, with the INTERNAL AMPLIFIER SWITCH to OUT. After tuning the selective amplifier using the phasemeter output meter as indicator, the phase etc. may be measured in the normal manner. For absolute voltage measurements the overall gain can be standardized by using the 50 c/s calibrating voltage provided by the phasemeter supply unit and adjusting the input attenuator of the D-669 or D-788 to give the correct output meter level. With the normal selectivity of the two Muirhead selective amplifiers it is possible to scale expand to 20° and read to 0·3° with 30% 2nd harmonic and 50% 3rd harmonic present in one channel only, this being the worst case. Using the increased Q facility of 150 available with the Frequency Analysers, the harmonic content can be greater than 100%. If a Muirhead-Pametrada D-489 Wave Analyser is available, then from 19 c/s upwards its greatly increased discrimination compared with the other Muirhead types mentioned allows the presence of a harmonic 30 times as large as the fundamental for 1° accuracy. In all these cases the voltage difference accuracy remains the same as before, i.e. ±0·2 dB or 2%. The absolute accuracy of level measurement will depend upon the constancy of gain with frequency of the selective device.

Other selective amplifiers may be used, provided that they have at least a gain of 1500 and suitable input and output impedances, viz. 100k ohms and not greater than 10k ohms respectively. Advice on this matter is freely available from the Company.

4. Measurements near to 90°

Occasions occur when it may be necessary to measure angles near to, but on either side of, 90°; for example, in the design of 90° phase-shift networks. It is then useful to have a meter scale which includes this range without operation of the sign-changer or quadrant switch. Such a scale can be obtained by first reversing the phase of the reference voltage, setting the quadrant switch to 0°–90°, 270°–360° and setting up the two channel voltages to half of full-scale reading, i.e. 10 on the 0 to 20 volt scale, instead of the normal $20/\sqrt{2}$ or 14·14V on the voltage scale. From Fig. 4 it will be seen that the reference vector OA has been reversed in phase to give OA_1, hence OC, the resultant, will increase from zero to twice OA_1 as θ varies from 0° to 180°. Now since OA_1 and OB have been made equal to half-scale reading then full-scale will correspond to 180°. Therefore no operation of the quadrant switch will be necessary beyond 90°. The scale will still follow the $\cos\frac{\theta}{2}$ law, with θ now varying between 0° and 180°, and hence $\cos\frac{\theta}{2}$ varying between 1 and 0. Remembering that the phase of the reference vector has been reversed, the scale will still be linear, but reduced, between 0° and 90°, but will close up between 90° and 180°. Around 90°, nevertheless, the scale is still open enough to read to 2 degrees, and it may be used for 10° either side with an appropriate correction. This can be made clearer by studying the comparative Table 1 on page 32. The first line gives the range 0° to 180°, with below it the corresponding scale readings on the output meter for the marked range 0° to 90°, whilst the third line gives the voltage readings on the 0 to 20 volts range. It will be noted that the closing up beyond 140°, whilst rapid, still enables readings to ±5° up to 170°.

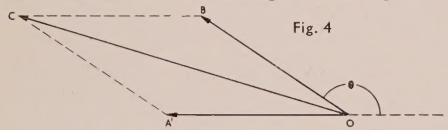

Fig. 4

SIGN CHANGER IN 0–180° SCALE

Naturally, the calibration also applies for the range 360° to 180°, and the phase-retard networks will still need to be used if the phase is to be measured 'round the clock' using this method.

5. Measurement of Power Factor of Capacitors

In Fig. 5 is shown an easily constructed bridge circuit for measuring the power factor of capacitors or dielectrics down to 0·0005. The method has possibilities since it can be used down to a few c/s and up to 100 kc/s where transformer circuits are unsuitable.

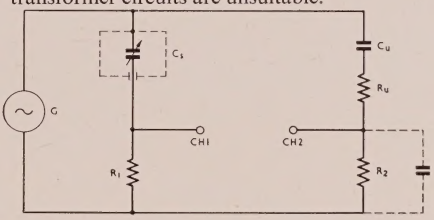

Fig. 5 MEASUREMENT OF POWER FACTOR OF A CAPACITOR

If capacitors C_v and C_s are equal, also R_1 and R_2, then the phase of the voltage across R_1 will be the same as that across R_2 provided that the power factors of the capacitors are also equal. By making C_s a good variable air capacitor, loss factor 0·0005 or less, this figure can be neglected and the power factor of C_v, the unknown capacitor, can be measured in terms of the phase difference between the voltages across R_2 and R_1. Furthermore, the accuracy will be at least 10% if $\omega^2C^2R^2$ is less than 0·1, and 1% if $\omega^2C^2R^2$ is less than 0.01. The phase angle in radians will be equal to the power factor, and since this should not exceed 0·1 even in a poor dielectric, the maximum phase difference

TABLE I Calibration for 0° to 180° Scale

Range	0 to 180	0	20	40	60	80	90	100	120	140	160	180
Corresponding	0 to 90	0	14·2	28	41·4	54	60	64·7	75·6	83·4	88·4	90
Voltage	0 to 20	0	3·47	6·84	10	12·9	14·14	15·1	17·3	18·8	19·7	20

required to be measured will not exceed 6°. Scale expansion can therefore be employed. For a power factor of 0·001, the angle will be 0·06° or 3·6 minutes which is still within the expansion limit of the instrument. As usual, in bridge technique, precautions must be taken in respect of component residuals including strays, and shielding must be employed for the standard air capacitor.

Capacitors from 50 pF to 1000 pF have been measured by this means in the frequency range 60 c/s to 50 kc/s by choosing suitable values of R. The test procedure consisted firstly of inserting a low-loss capacitor for C_v, of similar value to that required to be measured, and adjusting C_s to obtain minimum phase-angle, employing scale-expansion to the sensitivity demanded. Then the unknown capacitor was substituted for the low-loss capacitor and the phasemeter channels readjusted as required. For very low power factors a small air trimmer across R_2 was found to be required in order to obtain a sufficiently low residual reading. Under these conditions, it was found possible between 60 c/s and 50 kc/s to obtain a 'zero' of not more than 0·02 degrees. This residual was mostly noise and harmonics, for the use of a selective amplifier reduced the reading further. However, the selective amplifier was not necessary because the phase-shifts in the measuring circuit were almost the same for the two channels for harmonics as well as the fundamental; hence they also were almost completely cancelled.

6. Use with Inductors for Q and Power Factor

The measurement of the Q factor or magnification factor of an inductor presents some difficulty below the normal frequency of Q meters, usually 10 kc/s. Bridge methods become suspect for high Q's, whilst below 50 c/s the sensitivity rapidly disappears. Also transformers cease to be practical when used in bridges below this frequency. By using the two channels of the phasemeter to measure the input and output voltages in the familiar Q measuring circuit shown in Fig. 6, measurements down to the lowest frequency of the instrument may be made. The generator feeds a small resistor R in series with the inductor L and a low-loss

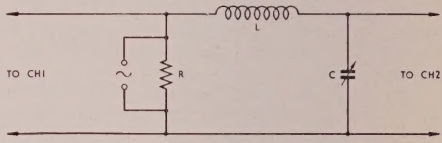

Fig. 6 MEASUREMENT OF Q OF AN INDUCTOR

capacitor C, preferably air or polystyrene dielectric. The capacitor C is tuned to give maximum voltage in Channel 2; then the ratio of Channel 2 to Channel 1 voltage is the Q factor. A great advantage of this method is that the input current to the inductor may be varied over a wide range and that Q's up to 20 000 are theoretically measurable.

(to be continued in next issue)

(continued from page 28)

possible to select bands remote from the interference frequency of 50 c/s and its harmonics, so that absolute measurements of the spectrum can be made, even when such interference is present. In these experiments the subject and battery-operated pre-amplifier were placed in an expanded-metal screening cage. This reduced the interference to a level at which it was not visible on the electromyogram on the cathode ray tube, but even so, large interference components could still be detected by the analyser as it was tuned through 50 c/s and 100 c/s.

The interpretation of the reading of a rectifier meter of the type used in the analyser is a difficult problem theoretically; a meter calibrated to read the root-mean-square value of a sinusoidal waveform will not necessarily read r.m.s. for other waveforms. What it reads will depend both on the precise nature of the waveform and upon the mechanical and electrical time constants of the meter and its circuit. The author has solved the problem experimentally by comparing the analyser meter reading with the reading of a thermocouple type of meter. The analyser meter was found to give the r.m.s. values correctly within a few per cent for the random noise and electromyogram waveforms.

CONCLUSION

Probably the widest applications of this type of wave analyser are to be found in the field of vibration analysis,[2] but the author's experience indicates that it is also a most useful instrument for the study of random waveforms. It is hoped that these remarks on the use of the analyser may prove helpful to others faced with similar problems.

References: [1]Joseph, J., Nightingale, A. and Williams, P.L. A detailed study of the electric potentials recorded over some postural muscles while relaxed and standing. J. Physiol. (1955), *127*, 617-625.
[2]Banks, B. D. Applications of the Muirhead-Pametrada Wave Analyser, Type D-489. *Technique 6*, April and July 1952.

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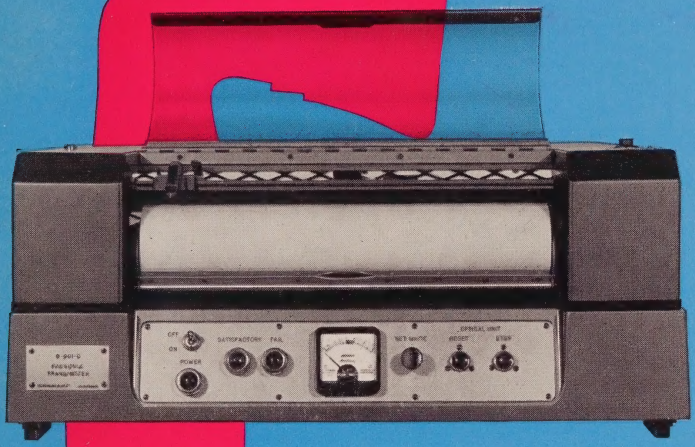

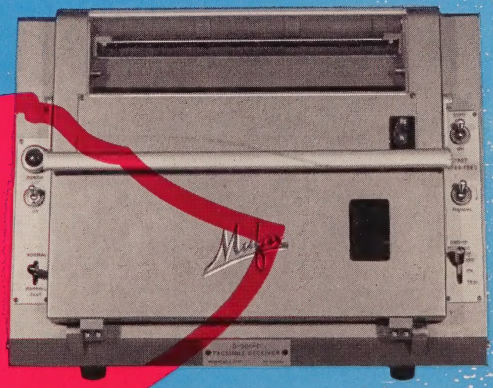

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THE FRONT COVER

The D-900/1 Mufax Transmitter and Receiver shown on our front cover are the latest facsimile instruments in the field of commercial communication.

These machines provide a ready means of transmitting a wide range of intelligence from one office to another or between branch offices; transmission may be effected over any distance using local or trunk telephone lines. The Business Facsimile System made possible by these machines enables handwritten messages, typescript, accounts, line drawings and sketches — in fact anything that can be expressed in black and white — to be transmitted in its original form with equal facility and what is perhaps of greatest importance, the received copy is a facsimile of the original and therefore completely free from transcription errors. Being almost automatic in operation, these machines meet the basic requirements of all office equipment, simplicity of operation and the ability to be operated by any of the office personnel, even the juniors.

MAGSLIP AND SYNCHRO DATA

The Synchro broadsheet announced in the January 1958 issue of *Technique* has had a very enthusiastic reception from engineers who appreciate the compact form in which the information is presented. In view of this a similar publication is being prepared for Magslips and will be available in the near future. Engineers requiring further information on any of the Synchros or Magslips listed in the broadsheets will be supplied with individual data sheets on the instruments concerned. Apart from this the issue of further individual data sheets for inclusion in existing Magslip and Synchro binders, and the issue of further binders, will be discontinued.

SYNCHRO TYPE NUMBERS

We have decided to 'streamline' the type numbers allocated to Synchros of Muirhead, as distinct from Bu Ord, origin. These type numbers originally of the form F15C-2-A/1 will now omit the 'F', also the dashes and oblique strokes, and the example cited will thus become 15C2A1.

SYNCHROS

In certain applications involving extreme vibration, customers have requested the elimination of slip rings and brushes from Synchros. To meet this requirement we have developed ligaments as an alternative rotor connection; the rotor movement is of course restricted to approximately $\pm 170°$. Problems involving the use of ligaments are being dealt with on an individual basis and designers wishing to use Synchros with ligaments are invited to discuss their requirements with our engineers.

APPLICATIONS OF THE MUIRHEAD PAMETRADA WAVE ANALYSER TO NOISE MEASUREMENT PROBLEMS

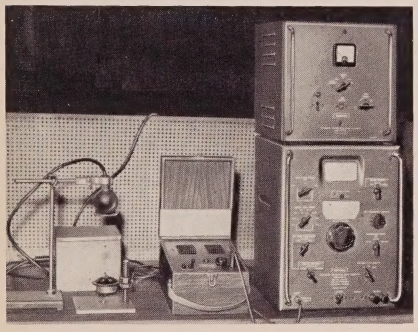
By J. S. Williamson *
B.A. (Oxon)

INTRODUCTION

The use of sound-level meters for the measurement of the loudness of a noise has two serious limitations both of which have to be overcome to enable any detailed noise investigation to be carried out. Firstly such instruments give no indication of the constituents of the sound being measured; although they contain frequency weighting networks to simulate the response of the human ear there is no visible indication of the frequency distribution of the noise. Secondly, they can be very misleading when the relative loudness of two different types of noise is required. Depending on the complexity of the noise the makers themselves admit that the scale reading can be several decibels in error. In short, the convenience of sound-level meters is often outweighed by their inaccuracies and the limited information they supply.

The only reliable way to measure loudness is to calculate it from a complete frequency analysis. The precise method of calculation varies from one type of noise to another and is still a matter of opinion in some cases. A few examples are given at the end of this article.

The Muirhead Pametrada Wave Analyser is the key to all the experimental work in this field.



Equipment for acoustic measurements on electric horn. Left: Moving coil microphone suspended above horn. *Centre:* D-630-C Valve-Maintained Tuning Fork. *Right:* D-489 Muirhead-Pametrada Wave Analyser and Power Unit.

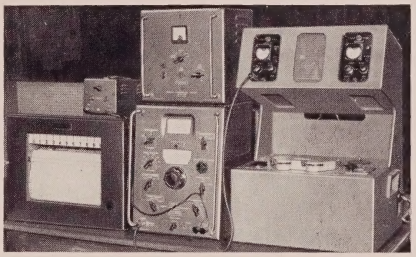
EXPERIMENTAL PROCEDURE

The procedure adopted is to a large extent dictated by the size and situation of the source of noise. In general the work falls into two sections.

(i) The picking up of the noise and the input to the analyser.

(ii) The recording of the output from the analyser.

The first part usually involves the use of a magnetic tape recorder, but there are some cases in which this additional apparatus can be dispensed with, for instance, when the source of noise is portable and small enough to be put in a sound-proof chamber and when its sound output is constant. In these circumstances there is no need to make a permanent record of the noise and the output of the microphone can be directly connected to the analyser. Provided that the calibration of the microphone is known, absolute values of the sound pressure at any frequency can be read off immediately. This method is applicable, for example, to small electric motors.



Set-up for analysing loop of magnetic tape. Right: Tape recorder. *Centre:* D-489 Muirhead-Pametrada Wave Analyser and Supply Unit. *Left:* Pen recorder with D-746 Impedance Converter above.

If, however, the source does not comply with both of the above conditions, or if, for any reason, it is better to carry out the analysis at some time after the generation of the noise and futhermore, if a permanent record is required for future use, then a magnetic tape recording must be made. Recordings are made on short loops of tape so that they can be played back continuously. Owing to the introduction of attenuation factors both on 'record' and 'play back' whenever a recorder is used, a standard signal is required to ensure correct gain settings to eliminate the attenuation. This standard signal is supplied from the Muirhead D-630-C Valve Maintained Tuning Fork which can be adjusted to give a convenient constant output. With each set of noise recordings is included one of the tuning fork and, when played back, the recorder controls are set so that the output from the tuning fork tape is the same as that from the fork direct.

The second part of the work depends on whether the noise consists solely of one or more fundamental frequencies together with their harmonics, or whether it is complex in so far as the peak frequencies have no relation to each other. In the case of a discreet frequency spectrum, e.g. an electric motor or a motor car horn, readings can be taken direct from the analyser once the fundamental frequency has

* Joseph Lucas Limited

been found. It is usually possible to calculate or guess from previous experience this frequency but, if not, it takes a very short time to find it after a cursory scanning with the frequency control in some anticipated range. At each harmonic the fine frequency control is adjusted for peak reading which is recorded, and if a diagrammatical representation is required it is plotted as in Fig. 1. Continuous frequency

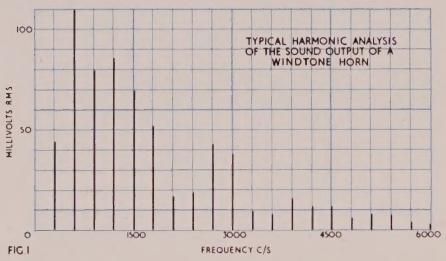


FIG 1

spectra, those for instance associated with the noise generated inside a moving car, are best obtained by using a pen recorder (see Fig. 2). The output from the analyser is connected through a Muirhead D-746 Impedance Converter whose low output impedance can feed the pen recorder. By manually synchronizing the tuning of the frequency control with the speed of the paper on the recorder, a linearly based spectrum is automatically plotted. Research is being done to make this process fully automatic. There is a limit to the speed at

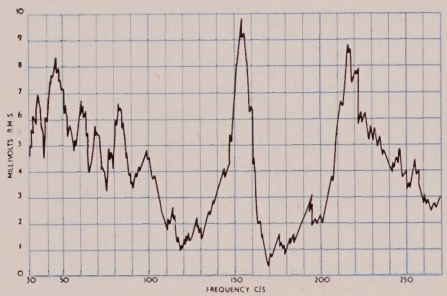


FIG 2 ANALYSIS OF NOISE GENERATED INSIDE A SALOON CAR WHEN FREE WHEELING OVER A ROUGH SURFACE AT 40 m.p.h.

which the frequency can be changed without loss of accuracy due to the inertia of the analyser needle but as interest is generally confined to a frequency range of a few hundred cycles per second this is not a serious handicap.

THEORETICAL PROCEDURE

Having obtained the frequency analysis it remains to calculate the overall noise level. The response of the human ear is so complicated that the formulation of any general mathematical rules is well nigh impossible. Although a large number of modifications have been suggested, one general method of calculation is as follows.

The spectrum is divided into bandwidths of half or whole octaves. Within each band the peaks in the case of the continuous spectrum or the individual harmonics in the case of the discreet spectrum are converted into dB from the calibration of the microphone. The dB's in each band are added logarithmically and this total value converted into phons at the mid-band frequency. The phon is the unit of subjective loudness and conversion from dB to phons is effected by using the Fletcher-Munson equal loudness contours, an experimental set of curves found in all acoustics textbooks. These phon values are then added by using another experimental table to give a final value for the loudness.

As long as noises of the same type are being compared there is no reason to doubt the validity of the results so obtained, but as soon as, for instance, a horn is compared with traffic noise, inconsistencies and unreasonable results begin to appear. Exactly how the ear reacts to a noise consisting of a fundamental note with several of its harmonics, like that of a musical instrument, is in some doubt.

CONCLUSION

Paradoxically the calculation of noise level from the experimental data is far more arbitrary than the data themselves. A reliable spectrum is easier to obtain than the loudness level to which it corresponds. The analysis of the sound as carried out by the Wave Analyser is considerably more accurate and uncontroversial than the subsequent theoretical treatment of loudness.

MUIRHEAD PICTURE TELEGRAPH SERVICE

by N. E. Maughan *

The growth of Picture Telegraphy during the last decade has been quite outstanding and at the present time practically all daily newspapers in Britain have at least one telephoto unit while some of the bigger organizations have several in both their London and Provincial offices.

Prior to World War II only a few machines, mainly of foreign origin were in use, and 'wired photos' (as referred to by the Press) were thus comparatively few in number and often sadly lacking in quality. Furthermore, the machines in use after hostilities ceased were rapidly nearing the end of their useful life and, because of the widespread devastation in Europe, replacements from the original suppliers were unobtainable. It was at this time that Muirhead were approached to develop high definition picture transmitters and receivers to fill the gap.

These new instruments, which comprised both static and mobile equipments, won immediate popularity, and within a year of being in production had established a reputa-

* Muirhead & Co. Ltd

tion for quality and reliability which soon spread abroad, resulting in orders from Sweden and other Scandinavian countries; soon to be followed by America, Italy, Australia, New Zealand and latterly South Africa, India, Eastern Europe and Russia.

It will be realized that if such machines are to continue to give service and maintain the high-quality transmission of which they are capable, the design must be inherently reliable and the construction and workmanship really sound. This is particularly true for mobile apparatus which must accompany the news photographer on his various assignments.

One occasion that comes to mind is the Antarctic Expedition of 1949 when one of our 'Portables' was carried by the Scandinavian party taking part; surely as gruelling a test as could be devised for any instrument.

By such tests of endurance the reliability of the Muirhead range of picture telegraph equipment has been established beyond question and has contributed in no small measure to its great popularity.

In addition to the Press, the Post and Telegraph services of numerous countries operate Muirhead transmitters and receivers, not only internally through their normal line networks but also over international radio circuits.

However, the best equipment requires some attention after a long period of operation, so an organization within the Picture Telegraph Test Department was set up to attend to this by making available the services of our engineers at short notice, arranging the supply of spare parts and giving advice or instruction to any users of our products. In this connection it is noteworthy that even when machines have been in continuous use for many years the number of requests for an engineer is relatively few. In most cases a telephone call enables any required replacement part to be despatched immediately, and, by reference to the comprehensive Instruction Manuals provided, to be fitted by the operators. If, however, the services of an engineer are imperative, immediate arrangements are made for him to start from the factory by the first available train or, if more convenient, by road, taking with him any spare parts likely to be needed.

It will be appreciated that in the case of news pictures, any delay (due to a machine failure) may render them valueless for a particular edition. Consequently immediate action by the Service Department is essential.

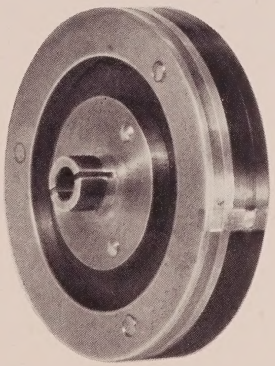
In the case of the Scandinavian countries immediate advice is provided by our agents on the spot, but should one of our engineers be needed he would leave on the first available flight. This happened on one occasion when a picture receiver had suffered accidental damage in Sweden: a few hours after the arrival of one of our staff, it was once more in full operation.

Naturally, when greater distances are involved — for example installations in Australia and New Zealand — this procedure is not practical; but again our agents in these countries are given all possible information in cases of reported failure, and any spare parts required can be despatched by air within a few hours of receiving a letter or cable, thus ensuring that no machine is inoperative for any appreciable length of time.

AND STILL IT WORKED (II)

We make no apology for repeating a title that appeared in Technique Vol. 8, No. 1. Then it related to the remarkable performance of one of our D-649 Facsimile Chart Transmitters; this time it is used in connexion with another type of Muirhead instrument — a timing device.

In 1953 we supplied to the Norsk Rikskvingkasting (Norwegian Government Broadcasting Administration) a timing device designed for the continuous transmission of a series of time signals in accordance with their specific requirements. After four years continuous use, during which time no breakdown had occurred, the machine, although working satisfactorily, was taken out of commission for a thorough overhaul. On inspection, the only noteworthy defect was a certain amount of wear on the surfaces of the contact drums which was not surprising since the one revolution-per-second drum, the fastest of three, had performed 125 million revolutions. The illustration, which was made from an un-retouched photograph, shows the extent of the metallic erosion caused by the platinum-iridium tipped brushes. For those who have an addiction for statistics we give the following approximate figures:



Running period: 4 years (35 000 hours)
Total revolutions of 1 rev/sec contact drum: 126 000 000
Total revolutions of driving motor: 1 260 000 000
Equivalent linear distance travelled by a point on the periphery of the drum (2 in. dia.): 12 500 miles (20 000 km).

DETERMINATION OF THE ANGULAR VELOCITY OF ROTATING STALL IN AN AXIAL FLOW MACHINE BY NOISE AND VIBRATION ANALYSIS

by

Prof. André L. Jaumotte, A.M.I.Mech.E.

Professor at the Brussels University
President of the Belgian Society of Mechanical Engineers

1. DESCRIPTION AND NATURE OF ROTATING STALL

Rotating stall is a phenomenon which appears in all compression turbo-machines, i.e. fans, blowers and compressors, axial or centrifugal, single or multi-stage, when the flow is reduced below a certain limit by throttling the output.

This phenomenon, unknown for a long time, assumed considerable importance when it was realized that it was responsible for certain blade failures in the axial compressors of jet-engines.

Rotating stall in a stage can be considered as the uniform propagation around the axis of rotation of stalled regions, i.e. regions of turbulance which tend to block the main air flow through the blading.

With respect to fixed axes, the stalled regions rotate in the same direction as the rotor but with a smaller velocity, of the order of 30 to 70% of the rotor speed. Therefore with respect to the rotor, the stall moves in the opposite direction, the relative velocity being the complement to 100% of the preceding ratio.

In some cases, the regions of stall extend from the root to the tip of the blade (total stall) while in other cases they only cover part of the blade height (partial or progressive stall).

Total stall is typical for short blades and usually there is only one region along the rotor blading. A notable feature of total stall is a discontinuity in the pressure-flow curve of the stage indicating that the onset of the stall is sudden. As the flow is decreased, the region of stall extends progressively until it covers the whole rotor. The angular velocity of the complete rotating stall is nearly constant and practically independent of the operating condition.

The partial or progressive stall is typical for long blades; depending upon the aerodynamic characteristics of the blades, it can exist either at the root or at the tip. An increase in the throttling (decrease of flow) causes a progressive tangential and radial spreading of the stalled regions together with *sudden* changes in their number and in the rotating stall velocity. In this case there is a peak in the pressure-flow curve but no discontinuity. The pressure decreases with the flow in the operating range with a partial stall.

The propagation of rotating stall can be qualitatively explained by considering the case of a cascade at high angle of incidence. Let us assume that for some reason (lack of accuracy in the machining or the setting of the blades, upstream perturbation) a set of blades stalls at a given time (Fig. 1). The space between the stalled blades is choked and the main stream by-passing the region, effectively increases the incidence of airfoil number 4 and decreases the incidence of the first airfoil of the stalled region, number 2. According to this model, the region will propagate along the cascade in the direction indicated in Figure 1.

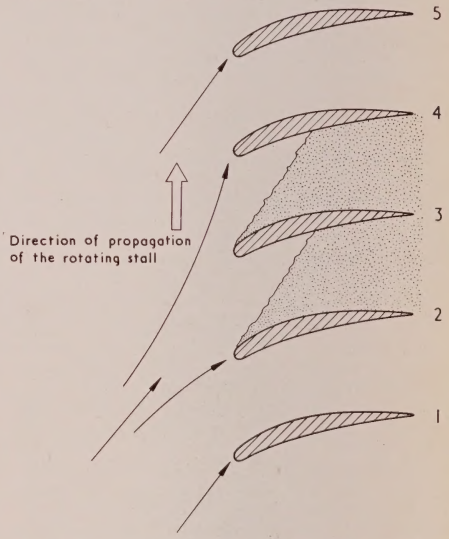


Fig. 1. Schematic representation of the stall in a cascade.

2. DISADVANTAGES OF ROTATING STALL

Rotating stall, acting periodically on the rotor blading, constitutes a source of excitation which in the case of resonance with one of the natural frequencies of the blading, may lead to fatigue failure of the blades by alternate stresses.

In the case of an axial multi-stage compressor, when the flow is reduced, the rotating stall appears in certain stages in the operating range of each isospeed and subsists until the complete stall is developed.

As pointed out by MM. Siestrunck, Fabri and Jarlan[1]: 'rotating stall appears in a rather

(1) Etude des régimes critiques non stationnaires dans le fonctionnement à vitesses réduites des compresseurs d'aviation. Paper presented at the "Journées Internationales de Sciences Aéronautiques" Paris, May 1957.

insidious manner in a multi-stage compressor, *because there is no corresponding important decrease in the performances*, no main flow or driving torque fluctuations, no acoustical anomaly discernible out of the overall noise from the test bench or from the engine, that could be used to detect it'.

In case of resonance, the induced stresses in the inlet stages of a compressor can lead to fatigue failures at low regimes.

rotating stall and the frequency of the stall can be immediately found.

The analysis is made by using a Muirhead-Pametrada Wave Analyser, referred to above, together with its adapter for low frequencies (D-652 Low Frequency Modulator).

Figure 2 gives part of the noise spectrum recorded in an axial-flow fan, at 1750 rev/min, before and after the appearance of the rotating stall, the angular velocity of which is equal to

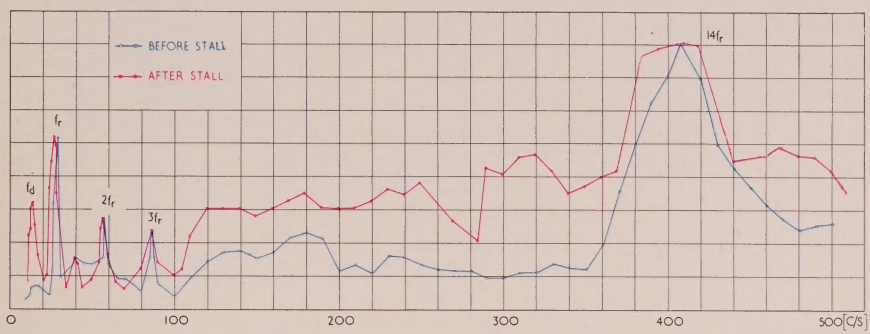


Fig. 2. Harmonic analysis of the noise of the rotor before and after stall (constant rev/min : 1750 rev/min).

3. DETERMINATION OF THE ANGULAR VELOCITY OF ROTATING STALL BY NOISE AND VIBRATION ANALYSIS

Rotating stall can be basically studied in a single rotor or in a rotor with guide vanes or with a diffuser.

The most important parameter to be determined is the speed ratio of the phenomenon, i.e. the ratio of the absolute angular velocity of the rotating stall to the angular velocity of the machine.

This ratio can be determined by anemometric surveys in the flow (hot wire anemometer placed upstream or downstream of the rotor) or by internal mechanical measurements (strain-gauges on the blades of the rotor).

The recording of the detected variable, transformed into electrical voltage, can be replaced by its harmonic analysis carried out by an analyser such as the D-489 Muirhead Pametrada Wave Analyser.

When there are several stalled regions, the measured frequency is equal to the number of stalled regions times the angular velocity of the rotating stall. The number of stalled regions may be determined by the use of two probes, the angular position of which can be adjusted.

The flow fluctuations due to the rotating stall induce both noise and vibration which can be used, in single-stage machines, to detect the product of the number of stalled regions and the rotating stall speed.

The method used at the Institut de Mecanique Appliquée of Brussels University, consists in the analysis of the noise picked up by a microphone or of the vibrations recorded by a suitable pick-up before and after the appearance of the rotating stall. By comparing the spectrographs, the peak intensity produced by 14 revolutions per second.

Figure 3 gives a detailed analysis of the noise and vibration in the region of the interesting

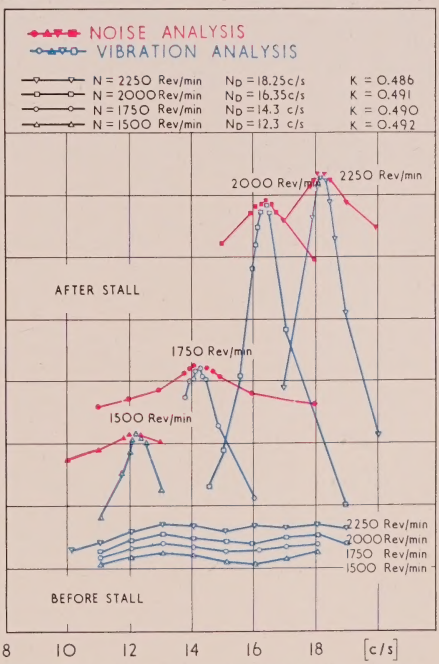
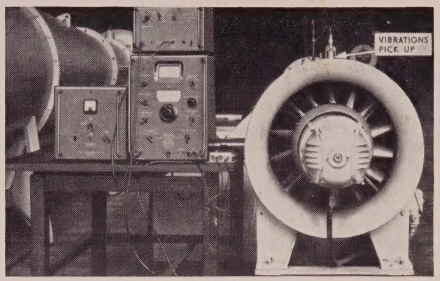


Fig. 3. Detailed harmonic analysis of the noise and vibrations before and after stall, in the region of the rotating stall frequency, for different angular velocities (analysis with constant opening).

frequency, with and without rotating stall, for different rev/min of the fan. It shows that the peak is well defined and that measurements can be accurately made. It should be noted that the noise intensity is not constant and for the measurement of its mean value, about 10 to 25 readings with the analyser are needed for each frequency, the readings being made at equally spaced time intervals (for instance 2 seconds).



Vibration measurements on axial-flow compressor. Right: Vibration pick-up mounted on compressor casing. *Left:* D-489 Muirhead Pametrada Wave Analyser and Supply Unit with D-652 Low Frequency Modulator above.

For vibration measurement, the pick-up is fastened to the envelope of the machine; this instrument gives a voltage which is proportional to the velocity of the vibrating element. The overall equipment is shown in Figure 4.

In conclusion, *the product of the angular velocity of the rotating stall, in a single stage axial machine, by the number of stalled regions can be determined from induced phenomena such as noise and vibration, by the use of an electrical harmonic analyser which analyses the pick-up voltage (microphone or vibration pick-up).*

INCREASED FACSIMILE SPEEDS FOR D-900 AND D-901 RECEIVERS AND TRANSMITTERS

There are many short distance facsimile applications in which sending speed is not limited by the transmission circuit and in which synchronized power supplies are available at transmitter and receiver locations. For such applications we have added to our D-900/901 series new models with a scanning rate of 360 scans/minute, which will transmit 4 inches of copy per minute at 90 lines/inch. The maximum document size is 14 inches by 8½ inches and the transmission time for 10 inches of copy is 2½ minutes.

The type numbers for these new models are:

Receiver D-900-H	Transmitter D-901-H
50 cycle operation	
Receiver D-900-J	Transmitter D-901-J
60 cycle operation	

INSTRUMENTS, ELECTRONICS AND AUTOMATION EXHIBITION OLYMPIA · LONDON · 16-25 APRIL 1958 STAND 600

In this year's I.E.A. Exhibition the Muirhead stand will occupy an island site on the ground floor of Olympia's Grand Hall. The wide range of Muirhead products to be shown will include something of interest to every visitor concerned with Instruments, Electronics and Automation.

The centre-piece of the stand will be an animated diorama representing a ship rolling heavily in a rough sea. At the throw of a switch the Muirhead Ship Stabilizer Control System is brought into operation and the ship's rolling motion is corrected as it would be under actual working conditions. The system that controls this model is the same as that installed in the *Queen Mary* and *Queen Elizabeth*.

Other exhibits, many of which will be shown as working demonstrations, will include INSTRUMENTS, TELEGRAPH FACSIMILE EQUIPMENT, SYNCHROS, LABORATORY EQUIPMENT and COMPONENTS.

TRANSFER FUNCTION ANALYSER

This equipment comprises a low-frequency decade oscillator, a phasemeter and a tunable filter.

At frequencies in the range 0·25 c/s–10 kc/s, the equipment provides — directly in polar form — the relationship between the input and output signals so that a Nyquist diagram can be plotted.

D-940-A MUIRHEAD-PAMETRADA AUTO ANALYSER

This comprehensive instrument is designed for the automatic analysis of vibration and noise waveforms — the output being plotted continuously on a recorder. The frequency range is 10 c/s–10 kc/s (fully automatic) and can be extended up to 19 kc/s by means of a manually operated switch.

Automatic analyses may be carried out in a number of ways using the programme control unit which forms part of the equipment.

D-788-B LOW FREQUENCY ANALYSER WITH AUTOMATIC DRIVE

Automatic waveform analysis down to 3 c/s is possible with this instrument. Total frequency range: 3 c/s–3000 c/s. Selectivity: Q-factor of 10 or 50 (Q factors up to 150 are obtainable).

MUFAX BUSINESS MACHINES D-900 RECEIVER AND D-901 TRANSMITTER

Long-distance transmission and reception of practically any type of document is possible with these new, inter-office facsimile instruments. All that is necessary to link the transmitter and receiver is an ordinary telephone line.

D-944 FACSIMILE TAPE RECORDER

This equipment overcomes many of the problems in relaying facsimile transmissions caused by temporary lack of line facilities or poor radio conditions. The D-944 Facsimile Tape Recorder enables facsimile signals to be recorded on magnetic tape for later transmission without loss of picture quality when conditions are more favourable.

SYNCHROS AND SERVOMOTORS

The Muirhead range of synchros and servomotors now covers more than 150 different types in frame sizes 08, 10, 11, 15, 18 and 23 — conforming to N.A.T.O., R.A.E., U.S. Military and Commercial Standards. New types appear continuously and the exhibits will include tacho-generators, size 10 servomotors, size 11 and size 15 torque elements, size 08 and size 23 synchros and a range of synchro resolvers.

D-881 HYDRAULIC RELAY UNIT

Designed specifically for industrial servo-applications, the D-881 Hydraulic Relay Unit is a self-contained hydraulic amplifier which operates from a mechanical input or an electrical input to a Magslip.

D-882 GYRO-CONTROLLED HYDRAULIC UNIT

This self-contained unit is specially designed to provide sufficient power to operate the main hydraulic machinery of a stabilizer system on a small ship or yacht of up to 300 tons.

The unit is controlled by a built-in Gyro and can be supplied with any one of three output torque and response time characteristics.

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THE FRONT COVER

Our Canadian Company, Muirhead Instruments Limited, was incorporated in July 1954 and moved from rented premises to the Plant pictured on the front cover on 1st December 1955.

The Plant was designed and built for the production of precision instruments similar to those manufactured at Beckenham; located at Stratford, Ontario, it covers nearly 20,000 square feet on a site of 20 acres.

With a Plant fully equipped with machine tools, each one the best in its class and staffed with highly skilled personnel, Muirhead Instruments Limited is already recognized in Canada as a manufacturer of instruments of superlative quality.

In addition to its own manufacturing activities, Muirhead Instruments Limited provides technical and maintenance services for the products of the parent Company.

The President of the Company, J Victor Foll OBE, is Managing Director of Muirhead & Co Limited; the Vice President and General Manager, A John Muirhead, is also a Director of the parent Company.

Muirhead Instruments Limited will develop its technical, manufacturing and servicing facilities to keep pace with Canadian requirements.

SYNCHROS

We have pleasure in announcing that we have been design-approved by the Ministry of Supply for the following classes of equipment:

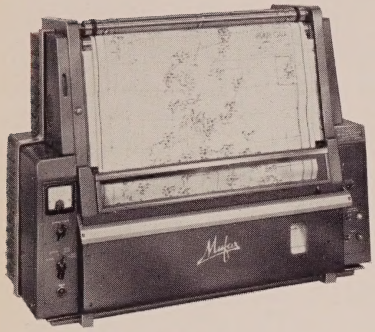
Synchros
Resolvers
Linear Variometers (Linvars)
Servo Motors
Tacho Generators
Servo Motor — Tacho Generators
Synchro Test Equipment

SERVO MOTORS

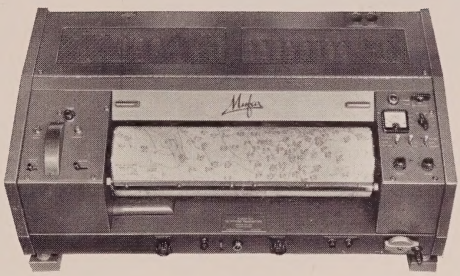
We now have available a size 08 servo motor. This instrument — $\frac{3}{4}$ in. diameter, only $1\frac{1}{8}$ in. long overall and weighing 1 oz. — has a stalled torque of 0·1 oz. in. and a no-load speed of 6500 rev/min. A data sheet giving further details is available on request.

WEATHER FACSIMILE BROADCASTS

by C. V. Ockenden, O.B.E., B.Sc., F.R.Met.Soc.*



D-649 Mufax 18 in. Chart Recorder



D-658 Mufax 18 in. Chart Transmitter

THE Commission for Synoptic Meteorology, the technical commission of the World Meteorological Organization which deals with meteorological codes and communications and co-ordinates the exchange of weather data throughout the world, held its second session in New Delhi from January 20th to February 15th. About 80 delegates were present representing some 37 countries.

The increasing importance of weather facsimile broadcasts was reflected in the discussions and in several recommendations which will be put to the meeting of the W.M.O. Executive Committee. The Commission endorsed the findings of its Working Group which has been studying the vital question of characteristics of weather-fax equipment and transmission systems in conjunction with the appropriate Study Group of the International Telecommunications Union. Compatibility is of paramount importance because broadcasts from main meteorological centres in various countries are required to be taken, the analysed charts so received being pieced together to give the weather forecaster a complete picture of the main systems of anticyclones, depressions, upper-air winds, etc. over the whole of the Northern Hemisphere. It will be appreciated that modern developments in aviation which have led to vastly increased speeds and ranges of aircraft demand that the weather forecaster's chart shall embrace extremely wide areas. The compilation of such charts using the older conventional method of collecting information in the form of coded five-figure groups and plotting it manually several times daily consumes an inordinate amount of man-hours and the final result cannot be so accurate as can be obtained from a composite chart based on the analyses produced by forecasters with specialized knowledge of conditions in their own particular region. It is of interest to note that the chief characteristics to ensure compatibility stem from those which were framed at a European regional meeting held in Stockholm in 1949.

The number of meteorological services already operating facsimile networks or experimenting with 'pilot' schemes, continues to grow. Amongst those countries represented at New Delhi were Belgium, France, W. Germany, Australia, Canada, U.S., Denmark, U.K., U.S.S.R., Sweden, Italy, Japan and India. The last-named has recently established a radio-fax network with the transmitting station located at Poona where the main forecasting and analysis centre is located and recorders are installed at Bombay, Calcutta and New Delhi. Subcarrier frequency modulation is employed and transmissions are made on three frequencies. During a tour of the Meteorological Office in Lodi Road, Delhi, delegates were able to see the MUFAX recorder and charts received from the Poona transmitter.

Considerable interest was shown in the matter of using facsimile for ground to air as well as ground-to-ground transmissions. Small light-weight MUFAX recorders are available which give excellent results with either weather maps or forecast diagrams. The employment of facsimile of course completely eliminates the hazards of 'garbling' which cannot be dissociated from radio teleprinter transmissions. During exchanges of views at informal discussions, delegates from facsimile-equipped services were also interested in the introduction of completely automatic recorders in the U.K. land-line network.

The greatest emphasis was laid on the necessity for the more rapid exchange of data and analysed charts between main centres in the Northern Hemisphere and a Working Group was established to study the question in detail and to produce draft recommendations before the next meeting. This will involve a study of the rôle to be played by facsimile, the use of which has been advocated to the maximum extent possible.

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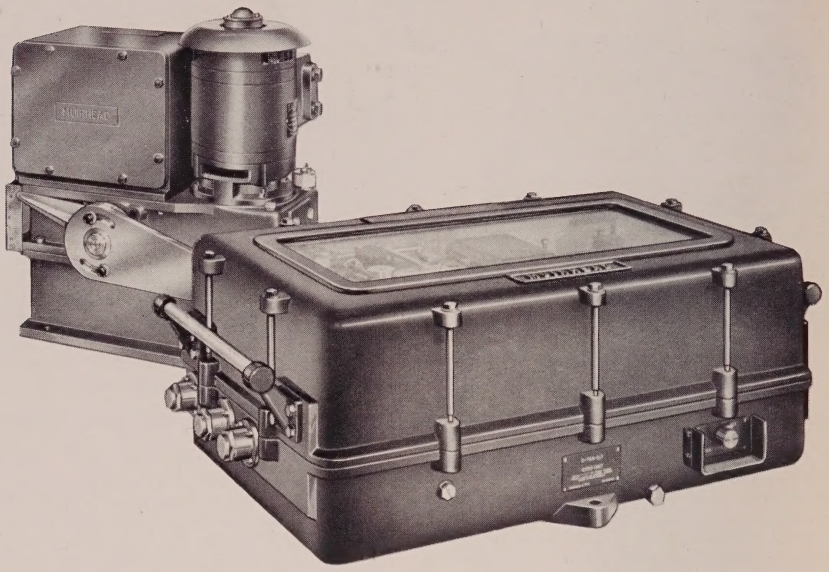
AN ANALOGUE COMPUTER EMPLOYING MAGSLIPS AND SERVOS

J. Bell, M.Sc., M.I.E.E.*



THE desirability of predicting the performance of control apparatus and in most cases contributing thereby to the information available for the final design, promotes the use of analogue computers. Such a computer may be wholly different in character, for example electronic instead of hydraulic, from the control equipment whose characteristics are being examined, or alternatively the computer may be designed to incorporate a considerable amount of the control apparatus to be used in practice. In such a case it becomes a working example, up to whatever point is practicable, of the control in question, and its behaviour is often more readily appreciated by observers than the equivalent electronic computer.

An analogue computer is here described constructed specially for Ship stabilization, the same technique however can doubtless be applied to other problems.

Other very good reasons for the use of a computer instead of attempting to test a full scale vessel are firstly the cost involved and secondly the weather, or sea disturbances are not available to order.

Ship stabilization involves apparatus for detecting the motion, or forces operating to cause the motion of a ship, this may be called the sensing or control apparatus. Following this, amplification must be employed to increase the power of the signal or output of the sensing apparatus, and in general, the amplifier employed consists of several stages of electrical or hydraulic equipment. The final output is adequate to function the stabilizing means, for example, fins in the case of a stabilizer of the Denny-Brown type, and may be of the order of 100 h.p. whereas the signal derived initially from the sensing means is of the order of one millionth of a horse-power.

Rolling Table

Assuming that the vessel when rolling will have a periodic motion, a table suitably mounted on bearings and oscillated by mechanical means at the required frequency and amplitude may be used to represent the ship, and on this may be mounted the sensing part of the control system together with the initial stages of amplification. The later stages of amplification are generally too large for mounting on a convenient rolling table. With a rolling table of this type the response of the stabilizing apparatus to a regular motion approximately sinusoidal in character can be determined. A little thought however will indicate that this is not an analogue and does not give much practical information because it does not 'close the loop'; in other words the table continues to roll taking no heed of the stabilizer signals and consequently its motion does not resemble the motion of a stabilized ship.

Additionally it has been observed in the case of a ship at sea, that the motion of the vessel, while it may be regular without the stabilizer functioning, generally loses its periodic character with the stabilizer in operation. The reason for this will be clear; when the signal from the

*Chief Research Engineer, Muirhead & Co., Limited

sensing equipment operates the stabilizing means, forces are developed which oppose the forces generated by the sea, and the motion of the vessel is due only to the difference in forces acting on the vessel. The difference being small by comparison with the two principal forces and almost inevitably irregular, the motion of the vessel is similar in character. Reasoning further on these lines it is apparent that the stabilized motion of the ship is now the motion which is generating the signals in the sensing apparatus, and consequently forces produced by the stabilizing means differ considerably from those which would be called for by sensing apparatus mounted on a freely rolling ship.

Two important points emerge from this reasoning; firstly, a continuously driven rolling table cannot adequately simulate a stabilized ship and secondly, the sensing apparatus must be sensitive enough to control fully the stabilizer, using only the small stabilized motion of the vessel (or simulated testing vessel) for generating the required signals.

Analogue Rolling Table

The rolling table must be sufficiently large to take the sensing apparatus, one or more stages of intial amplification, together with an equipment simulating the actual stabilizing means and the final amplifier associated with that means. A block diagram of this arrangement is shown in Figure 1.

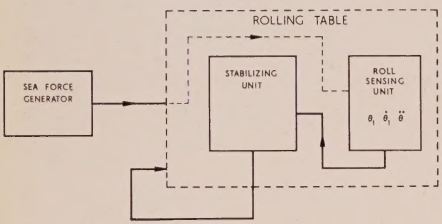


Fig. 1. Block diagram of analogue rolling table.

The dotted line shows the boundary of the rolling table corresponding to the ship. It contains the sensing unit whose output operates the stabilizing unit; the output from the stabilizing unit is shown as reacting on the rolling table. The sea force generator is also shown acting on the rolling table. Thus, the nett force operating on the rolling table is the difference between the sea forces and the stabilizer output. The table thus represents in analogue and on a reduced scale, the vessel under stabilized conditions. Breaking the control link between the sensing unit and the stabilizing unit cuts out the stabilization, and the table will roll freely under the influence of the sea forces. To get an exact reproduction of the vessel's movements, various factors in the construction and operation of the table require particular attention.

Examining first the requirements of the table alone, it must be mounted on free bearings which will impose on the motion of the table less friction than the equivalent damping of any vessel which is to be simulated. The table should be capable of being loaded with any equipment, statically balanced, and then pendulously loaded so that it represents a ship in periodic (sinusoidal) motion. The damping can then be adjusted by means of a suitable brake or by viscous damping to represent the ship in an unstabilized condition. A typical decrement in rolling motion with natural damping only is of exponential form such that, in two complete rolls the amplitude of rolling decreases to half value.

Sea Forces

The table must also be provided with a means of simulating the sea forces acting upon the ship; this can be done by means of a moving weight so arranged as to apply torques about the operating centre of the rolling table. The weight is preferably located so that its movement from one position to another, which involves acceleration, does not impose thereby additional rolling torque on the table. The weight therefore should move (with the table horizontal) in the horizontal plane containing the rolling axis of the table and, in the design now being described, the motion is also at right angles to the rolling axis. If such a weight is moved in a sinusoidal manner the effect will be to produce on the table a sinusoidal torque, and if the motion of the weight is tuned to correspond in period with that of the table, a large roll amplitude will result corresponding roughly to six times the static deflexion of the table produced by the maximum moment due to the moving weight. (This assumes the same damping factor as quoted above.)

Inputs other than sinusoidal motion can be readily achieved by operating the weight in a suitable manner by a servo system. For this purpose a cam device has been arranged consisting of a 12-inch diameter wheel divided into sixteen sections. In each of these sections can be inserted a piece of Bakelite or similar sheet material whose contour is cut according to the desired waveform. Thus, for example, six sections of sinuoidal form might be inserted in sequence followed by a section of zero curvature or 'calm water', followed again by the simulation of a single wave or by sinusoidal waves of varying amplitude and of a frequency differing from the frequency of the rolling table. Step impulses may also be applied. The cam follower consists of a small roller carried on the end of a lever which is arranged to turn the rotor of a Magslip or Linvar forming the input to the servo system, the mechanical output from which moves the weight. The weight then follows the contours on which the cam wheel runs.

An alternative arrangement which was considered consisted of an optical method of curve following in which a servomotor would copy a curve drawn according to the desired sea force. Coupled to the servo would be a Magslip Synchronous Link Transmitter suitably geared up, and connected to it a receiver mounted on the rolling table. Because of its relatively high

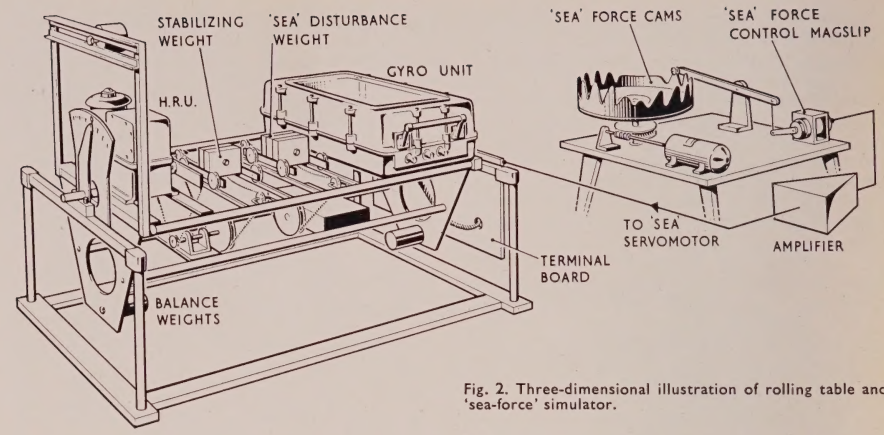


Fig. 2. Three-dimensional illustration of rolling table and 'sea-force' simulator.

ratio the receiver would operate the required excursion of the weight without sensible lag. The form of wheel and cam arrangement as described was used instead, however, because operation from the mechanical cam seemed more positive and did not involve illumination and the sensitive circuits usually associated with an optical following device.

The characteristics of the rolling table are such that it can be loaded with the appropriate stabilizing equipment and tuned over a range of 4 seconds to 30 seconds periodic time and the servo is arranged to be fast enough to apply the full sea force in something less than one second.

Operation

Operation of the equipment is relatively simple. After inserting the desired contours in the cam wheel it is started up and timed in speed of rotation to correspond with the desired rate of application of the waves. With the stabilizer equipment out of action, measurements of the free rolling of the table can be taken. The stabilizer equipment can then be switched on and the same sequence of sea forces applied, the result being a very close simulation of a large vessel under stabilized conditions. The gain due to stabilization is very strikingly demonstrated by this means.

Permanent results are most conveniently obtained by means of a recorder, Magslips are fitted to follow the motion of the table and also the motion of the stabilizing means, and these are recorded side by side on an appropriate chart. The time taken to make the required measurements is only a matter of minutes. Changes in the characteristics of the sensing apparatus and the subsequent amplifiers can be made, and the significance of these changes recorded and examined thereby assisting in the development of the control system as a whole.

Figure 2 shows diagrammatically the arrangement of the whole of the testing equipment and Figure 3 is a plan of the rolling table showing the disposition of the weights and the stabilizing apparatus.

Reproductions of roll records are shown in Figures 4 and 5. Figure 4 represents a ship having 5° fin power and being rolled with a $5\frac{1}{2}$° wave-slope. The 'sea' employed is a combination of two wave periods each being tuned in turn to the ship's period of 10 seconds. The considerable contrast between free rolling and

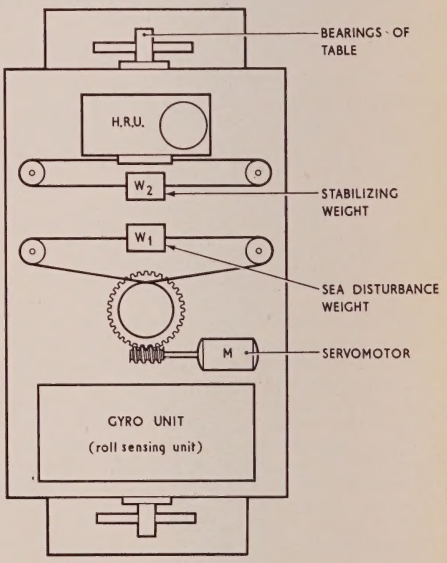
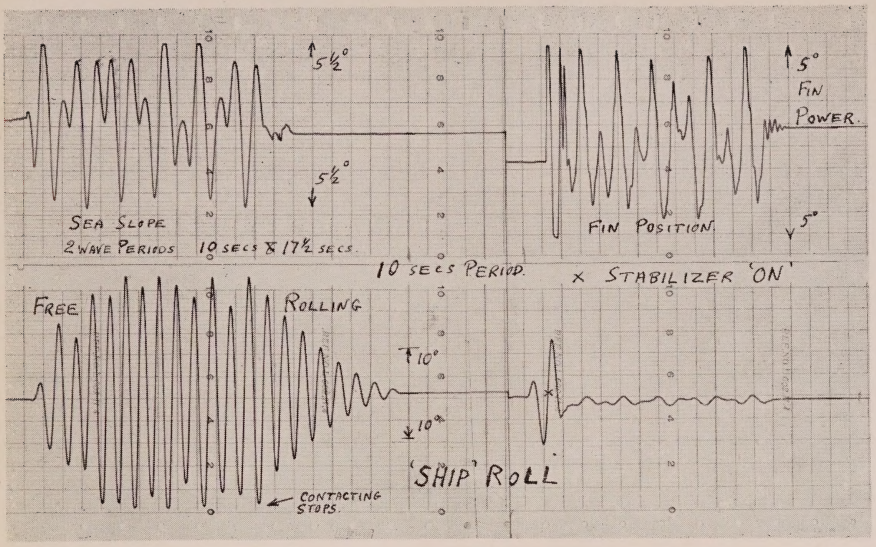


Fig. 3. Plan of rolling-table showing disposition of weights and stabilizing apparatus.

the stabilized ship movement is clearly seen, and it is interesting to observe how the fin position copies reasonably well the force of the sea.

In Figure 5 the effect of individual waves, again both with free rolling and with the



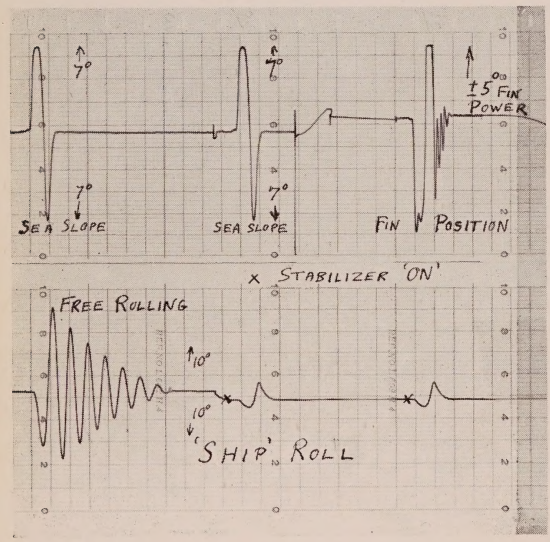


Fig. 4. (above): Ship roll caused by 'confused' (non-sinusoidal) wave motion under 'free rolling' and 'stabilized' conditions.

Fig. 5. (left): Effect of single wave on ship motion under 'free rolling' and 'stabilized' conditions.

stabilizer on, are shown. The wave-slope is reproduced twice so that the ship's roll under stabilized conditions can be registered with the wave-slope and corresponding registration be noted for fin position. The disturbing waveform employed was empirically shaped to give the largest ship movement for a single wave; the first half has a longer period than the second, the whole occupying approximately 13 sec. instead of 10 sec.

The sensitivity of the setting of each function of the control was normal for these tests. It is possible in a given vessel, however, that the sensitivity of the acceleration function, for example, might be reduced and the sensitivity of the velocity function increased. The final adjustment of these controls depends on whether it is desired to get the smallest possible ship movement under stabilized conditions or to have a 'smooth' ship movement with a slightly larger amplitude.

In the above analogue tests complete simulation of the lags in the large fin operating equipment was not represented.

Long Term Stability Tests on D-603 Tuning Forks

By J. A. B. Davidson, M.A., A.M.I.E.E.*

IN April, 1954, regular frequency checks were started on three D-603 1000 c/s tuning forks. These tuning forks and their maintaining amplifiers are standard production types and have now been running continuously for four years. Readings were taken twice per week until October, 1955, then once per week until the end of 1957, and the tests are continuing with measurements once per fortnight. In the space available here, it is not possible to show all the information obtained, but the condensed graphs in figure 1 show the general pattern of events.

In figure 1 the three curves relate to the tuning forks A, B and C and show plotted against time the frequency deviations in parts per million from the standard frequency of 1000 c/s. Prior to the commencement of the tests, forks A and B were given repeated heat cycles up to 70°C; in the case of fork C this final treatment was omitted. The frequency deviations in the graphs are plotted at intervals of approximately two months and do not display the maxima and minima of the recorded readings. These values for each fork however, are shown at the right hand side of figure 1. It will be noticed that during the first eighteen months the waviness of the curves is not pronounced, although fork B exhibited an upward trend in the initial stages until it stabilized at about 10 parts in a million high. From late 1955 onwards, the variations are somewhat larger. This is accounted for by the fact that the temperature co-efficients of the forks have varied somewhat over the years, as shown in the following table:

Temp. Co-efficient (parts in 10^6 per °F)

Date	Fork A	Fork B	Fork C
mid 1954	−0·3	−0·1	−0·35
mid 1955	−0·5	−0·35	−0·7
Feb. 1956	−0·9	−0·65	−1·2
July 1956	−0·55	−0·45	−0·8
June 1957	−0·25	−0·8	−1·2

Maximum and minimum readings of temperature, relative humidity and mains voltage recorded during the tests were as follows:

Ambient temperature	61°F – 88°F
R.H.	30% – 79%
Mains voltage	210V – 227V

Temperature is the only one of these three parameters which shows correlation with the fork frequency variations. Forks B and C exhibited their highest frequency on 13th Feb, 1956 at 61°F. and their lowest frequency on 17th June, 1957 at (88°F.). Fork A was at its lowest on the 9th July, 1956 (87°F.) and at its highest on 26th Nov, 1956 (62°F.). The 17th June, 1957 readings appear on the graph (Fig. 1) and it is clear that at this date fork A was showing smaller variations than the other two. This is due to the fact that at this period its temperature co-efficient was low.

Throughout the four-year period the reliability of the forks was extremely good. Only two valve changes were made. Both of these were in the fork A amplifier at the end of 1954 and produced no observable effect upon its frequency. All the valves involved have therefore completed at least 25 000 hours service.

The long term drift due to ageing of the fork tines and magnetic assembly. has been very small. Fork A has shown negligible drift, forks B and C drifted 10 and 8 parts in a million respectively during their first eight months, but since that time the drift of both these forks has been insignificant. This performance is markedly superior to that of forks manufactured in the immediate post war period, and is due to improvement in materials and in heat treatment and pre-ageing techniques. The initial drift of forks B and C could have been corrected by adjustments provided within the amplifiers, but it was laid down at the start of tests that no adjustments were to be made.

Forks A and B have remained within the ±10 parts in a million of their mean frequency for the past three years. Fork C has shown slightly greater deviations. This may be due to the omission of heat cycling. The greatest deviations occur at periods when maximum temperature changes coincide with an increase in temperature co-efficients to a figure around 1 part in 10^6 per °F. Attention is now being directed to means of stabilizing the temperature co-efficient.

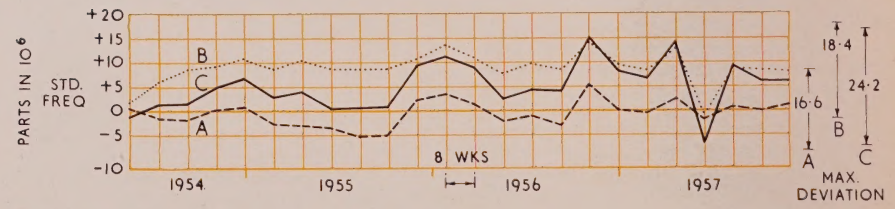


Fig. 1

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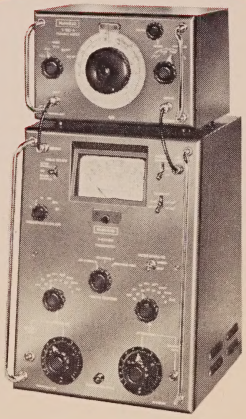

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THE FRONT COVER

The design of our front cover symbolizes a class of measurement which, because of the rapidly expanding use of automatic control techniques, has assumed a position of major importance; we refer to the frequency response testing of servo systems.

The equipment illustrated comprises the D-729-B Low Frequency Phasemeter (0·25 c/s–10 kc/s), the D-925 Tunable Filter (0·5 c/s–10 kc/s) and the D-638-B Muirhead-Wigan Low Frequency Decade Oscillator (0·1 c/s–2 kc/s) which together form an accurate, easy-to-operate and reasonably priced Transfer Function Analyser.

The core of the equipment is the D-729-B Low Frequency Phasemeter; it gives direct indication on a meter of the phase angle (0–360°) and amplitude difference (up to 70 dB) by attenuator readings between the signals at any two points of the system under examination. From these measurements it is a simple matter to derive the transfer function of any linear system, and since the phase difference between the input and output is directly observed, polar response curves including the Nyquist diagram may be easily plotted without the need for extensive and time-consuming calculations to convert from Cartesian to polar co-ordinates. The minimum input signal for either channel is 5 mV.

For use when either of the test voltages is distorted, the D-925 Tunable Filter (seen on top of the phasemeter) can be used in association with the phasemeter. The unit is tunable between 0·5 c/s and 10 kc/s and may be used separately in its own right as a very efficient rejection filter.

As part of the Transfer Function Analyser the D-638-B Muirhead-Wigan Low Frequency Decade Oscillator (the instrument on the left of the illustration) is required where it is necessary to provide an external sinusoidal input of variable frequency to the system under test. A notable feature of the equipment is that measurements of phase angle and level difference can be made without reference to the oscillator output.

SYNCHROS AND SERVOMOTORS

The Muirhead Synchro Broadsheet announced in the January 1958 issue of *Technique* has recently been re-issued to include the latest additions to our already extensive range of Synchros and Servomotors.

Also available (but not included in the broadsheet) are the following new 60 c/s servomotors:

18M10B4 Servomotor in Size 18 (Mark 8 Mod 1) frame

15M10A4 Servomotor in Size 15 (Mark 7 Mod 1) frame

These servomotors will function satisfactorily on 50 c/s supplies.

AN APPLICATION OF THE RECIPROCITY THEOREM TO THE CALIBRATION OF ACCELEROMETERS

By J. R. H. Lewis, A. Inst. P.*

The development of high speed engines, delicate electronic equipment and precision instruments of all kinds, have led to the need for greatly improved techniques for the isolation of vibration frequencies. Parallel with this has come the demand for sensitive and reliable vibration pick-ups, bringing in its turn a more stringent requirement for accurate methods of calibration over a wide frequency range.

Many problems require analysis over a band of only 0–100 c/s, but it is now appreciated that in dealing with undesirable features such as valve microphony, the generation of airborne noise and the transmission of structure borne vibration in buildings, aircraft and ships, high frequency response characteristics must be investigated.

Measuring Technique

The measurement of vibration at frequencies up to 10 kc/s is usually effected by means of transducers in the form of piezoelectric crystals. Electrically polarized barium titanate is a ceramic material possessing this property and having an output e.m.f. proportional to the acceleration applied to it. The crystal has a very high internal impedance and usually requires the use of a head amplifier in the form of a cathode follower to provide for signal transmission over distances of up to 500 ft. The signal is fed to a suitable measuring device through a high gain amplifier. In most cases the specimen under test will be found to have a frequency spectrum extending over a wide range and it is usually necessary to break this down in terms of third octave bands or discrete components. Accurate measurement of vibration depends not only on the quality of the instruments used but on the calibration of the transducer. Few methods of calibrating at high frequencies are available, but of these probably the most effective is that of the reciprocity technique. The method here described is due primarily to H.M. Trent.

Calibrations by the Reciprocity Method

In one of its simpler forms the reciprocity theorem states that if a constant-current generator i is connected to a linear passive electrical network and an open circuit voltage e is measured at some other accessible part of the circuit, then, as a second experiment, if the same constant-current generator i is connected to this part of the circuit, the same open-circuit voltage will be measured at the terminals where the generator was originally connected. The theorem can be applied equally well to linear, passive, reversible electro-mechanical systems.

If the sensitivity, S, of a transducer as a voltage generator be defined as

$$S = e/u \quad \ldots\ldots\ldots (1)$$

Where e = open-circuit voltage output
and u = velocity of input side

If, further its sensitivity G as a force generator be defined as

$$G = f/i \quad \ldots\ldots\ldots (2)$$

where f = output force with mechanical side blocked
and i = input current with mechanical side blocked

then it can be shown by the reciprocity theorem that for an electrostatic transducer

$$S = G \quad \ldots\ldots\ldots (3)$$

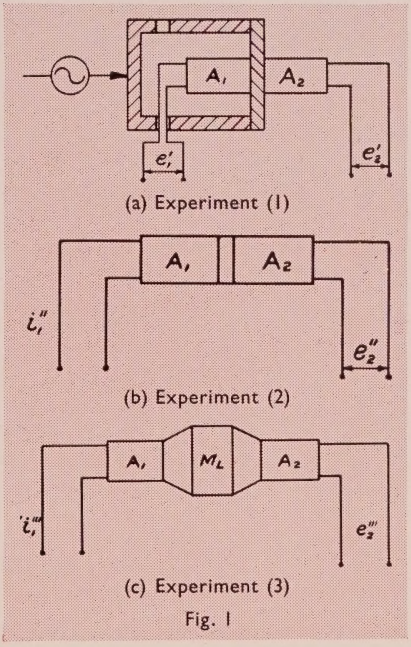

Fig. 1

This relationship provides the key to the system of calibration now to be described. The method requires the use of two reversible transducers A_1 and A_2 having sensitivities S_1 and S_2 respectively; an electrodynamic vibration generator driven by a high quality oscillator and a discrete frequency wave analyser. The Muirhead-Wigan Decade Oscillator D-650-B and the Muirhead-Pametrada Wave Analyser D-489-EM have been found eminently suitable. Basically the procedure reduces to three experiments (Figs. 1 a, b and c) each involving the measurement of a simple ratio.

*The Admiralty Engineering Laboratory

(1) *Ratio of Sensitivities*

In this experiment A_1 and A_2 are rigidly fixed to opposite faces of a vibrating element and excited at appropriate frequency intervals over the range 0·5 to 20 kc/s. At each frequency the output from each accelerometer is fed through the same measuring channel described above and the ratio of their open-circuit voltage determined. This is done by the null point method using the high quality attenuator provided in the D-489-EM Analyser. The result can be expressed in the form

$$S_1/S_2 = e_1'/e_2' \quad \ldots\ldots\ldots \quad (4)$$

where e_1' and e_2' are the respective open-circuit voltage outputs of A_1 and A_2. The single primes denote experiment (1).

and the reciprocity relationship of equation (3) reduces this to

$$S_1^2 = \frac{e_1'}{e_2'} \cdot \frac{j\omega M_L}{[(i_1'''/e_2''') - (i_1''/e_2'')]} \quad \ldots\ldots \quad (6)$$

To express the sensitivity of A_1 in terms of acceleration it is only necessary to multiply (5) by $1/j\omega$ giving

$$S_1 = \sqrt{\frac{e_1'}{e_2'} \cdot \frac{jM_L}{[(i_1'''/e_2''') - (i_1''/e_2'')\omega]}} \quad \ldots \quad (7)$$

All the quantities in this equation are known. If the mks system is used the sensitivity will be expressed in (volts) $\times$ (meters) $^{-1} \times$ (seconds)$^{-2}$. A typical calibration result is shown in Fig. 4.

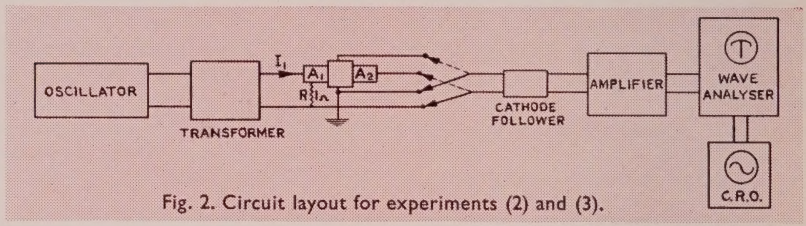

Fig. 2. Circuit layout for experiments (2) and (3).

(2) *Ratio of Input Current i_1'' to output voltage e_2''*

In this operation the accelerometers A_1 and A_2 are rigidly attached to opposite faces of a small metal coupling unit freely suspended from a suitable support. The decade oscillator is then made to drive the accelerometer A_1 through a voltage transformer having a step-up ratio of about 3 to 1. Since the transducers are reversible an alternating mechanical force is thus applied to the whole system causing the generation of a voltage output e_2'' from A_2. The current input i_1'' to A_1 is measured by tapping off the voltage drop across a one ohm resistance in series with the input and feeding it through the same measuring channel used for e_2''. In this case the primes denote experiment (2). The circuit layout for this experiment can be seen in Fig. 2.

(3) *Ratio of Input Current i_1''' to e_2'''.*

Here again the triple primes denote experiment (3). This is merely a repeat of the previous one except that in this case the coupling unit is replaced by a rigid mass M_L some ten times that of the total mass of the system used in experiment (2). A photograph of the instrument layout is shown in Fig. 3.

Space does not permit a detailed explanation of the theory of the procedure but it can be shown by means of the mobility analogy method of treating dynamical problems that the mobility of the additional mass M_L can be expressed as

$$G_1 S_2 = \frac{j\omega M_L}{(i_1'''/e_2''') - (i_1''/e_2'')} \quad \ldots\ldots \quad (5)$$

where $\omega = 2\pi \times$ applied frequency.

Substitution of the results of experiment (1)

Precautions

It can be seen from Fig. 4 that the lowest frequency reached is 500 c/s. This limit is not absolute but depends on a number of factors which include the mass of the accelerometer alone, the value of M_L and the sensitivity of the measuring instruments. Whilst M_L must be considerably greater than the combined mass of the accelerometers and their coupling unit, it must not be too large, otherwise excessive energy will be absorbed in Experiment (3). In addition to this a mass of larger dimensions introduces an error at high frequencies due to the departure of its effective mass from linearity. This is responsible for the steep rise in sensitivity above 12 kc/s as seen in Fig. 4. A resonant condition is found to occur at about 20 kc/s.

It is also desirable to avoid applying very high voltages to A_1 at the lower frequencies as this may induce large linear strains in the transducer crystal. In the particular calibration represented in Fig. 4 about 270 volts was the maximum e.m.f. applied at 500 c/s.

It will be appreciated that only very small energies are operating through the accelerometers and mass, thus demanding the use of instruments having a very high gain. This requirement, of course brings with it the tribulations of unwanted electromagnetic coupling and earth loops. As seen in Fig. 2 the only earth point is at the unit linking the two transducers. Leads should be carefully screened and a check made to insure that the output from A_2 is really due to the applied mechanical excitation of A_1 and not to electromagnetic pick-up. This can usually be demonstrated by disconnecting A_2 mechanically from A_1 whilst maintaining electrical contact by means of a flexible lead. In

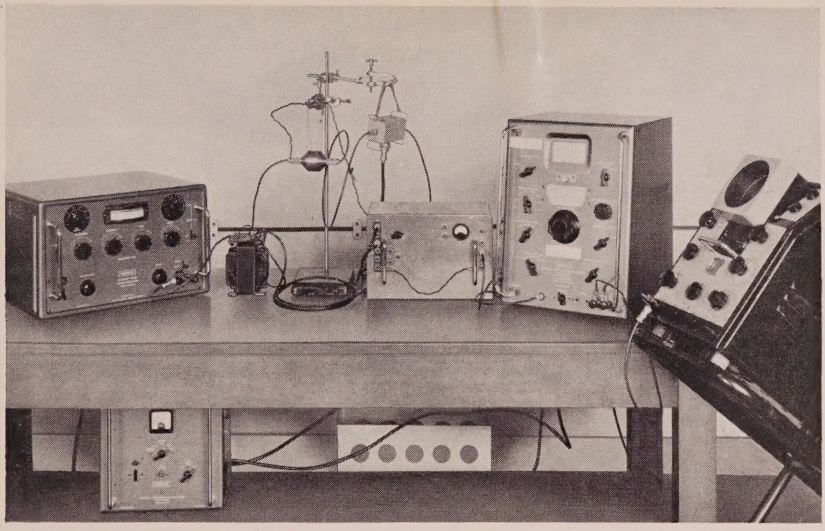

Fig. 3. Instrumentation for experiments (2) and (3).

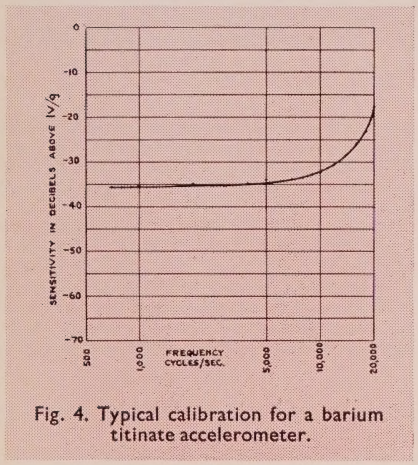

Fig. 4. Typical calibration for a barium titinate accelerometer.

this condition the output signal should drop to zero.

It is also important to monitor the waveforms operating in the system, especially that from the pick-up A_2. Due to the sharp resonant peaks occuring at 20 kc/s (and higher) referred to above it is often found that harmonics of the driving signal are sufficient to excite these peaks to values which dominate the output level of A_2. Hence the need for a high quality oscillator giving as pure a sine wave as possible. On a meter reading total levels only this would clearly lead to errors and hence a discrete frequency analyser is essential if the unwanted components are to be filtered out.

Conclusions

It is hoped enough has been said in this brief account to indicate that the reciprocity system of calibration is quite straightforward and only requires the use of two high grade instruments. Other rather intricate methods do exist for this range of frequencies but none are perhaps quite so easily applied as the reciprocity technique whose elegance lies in the fact that only three ratios need be measured and the value of a mass and resistance determined.

When coupled with optical calibrating procedures capable of working up to 500 c/s, which is not unusual, the reciprocity technique provides for the establishment of a standard over a frequency range limited only by the first resonance of the electro-mechanical system employed. By the simple method of comparison transducers of any type may then be calibrated against this standard.

Although this account is considered sufficient to form a working basis for carrying out a reciprocity calibration, more detailed descriptions and explanations are available in the references given below. The author wishes to thank Mr. P. Pearson for his valuable assistance in setting up these experiments and the preparation of this manuscript.

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[1] 'The Absolute Calibration of Electro-Mechanical Pick-ups', by H. M. Trent, Journal of Applied Mechanics, March 1948.

[2] 'Reciprocity Calibration of Piezoelectric Accelerometers', by M. Harrison, A. O. Sykes and P. G. Marcotte, Journal of Acoustical Society of America, Vol. 24, No. 4, July 1952.

A TECHNIQUE FOR MEASURING THE VELOCITY OF SURFACE VIBRATIONS

by R. Jones* and E. N. Gatfield*

General view of equipment in use on soil surface.

A SUSTAINED vibration technique has been developed at the Road Research Laboratory as a non-destructive test for estimating the thickness of existing concrete road slabs[1] and to study the mechanical properties of soil formations before road construction[2]. This article describes more fully the experimental technique and apparatus used.

Basically, the technique entails the propagation of surface vibrations in the road structure or soil and the determination of the wavelength of the vibrations. A vibration generator is placed on the surface and is operated at specific frequencies within the range of 40–60 000 c/s. At each test frequency, a vibration pick-up is moved along the surface, and measurements are made of the distances at which the vibrations have the same relative phase, i.e., wavelength positions or, where there is a difference in phase of 180°, half wavelength positions. The phase velocity of the vibrations is obtained from the product of the wavelength and the frequency; its variation with frequency depends on the thickness and elastic properties

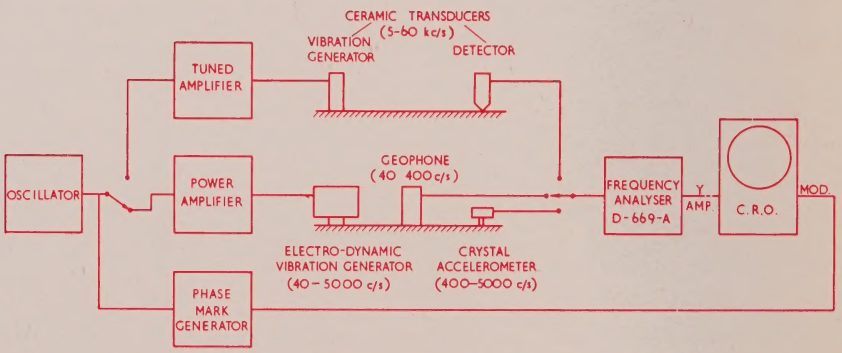

Fig. 1. Schematic diagram of apparatus.

*Road Research Laboratory, Department of Scientific and Industrial Research.

of the road structure. The interpretation of the results has been discussed in the previous references ([1] and [2]).

EXPERIMENTAL TECHNIQUE

A schematic diagram of the apparatus is shown in Fig. 1: different types of vibrator and pick-up are used for different parts of the frequency range.

Below 5000 c/s, the vibrations are produced by an electro-dynamic vibration generator driven by an oscillator and a power amplifier; details of the vibration generator are given in Fig. 2 and specifications for the generator, oscillator and power amplifier appear in Table I. The oscillator also feeds into a phase-mark generator which squares and differentiates the waveform and ultimately produces a voltage pulse once per cycle as shown in Fig. 3. The voltage pulse is used to suppress the beam of the cathode-ray oscilloscope and so provide a reference mark which is fixed in relation to the phase of the vibrations produced by the generator.

The vibrations are received by a vibration pick-up, whose output is amplified and applied to the vertical deflection plates of the cathode ray oscilloscope. Thus the waveform of the vibrations is displayed on the oscilloscope with the reference mark appearing as a short break in each cycle (see Fig. 3). In the present apparatus a geophone is used as the vibration detector at frequencies below 400 c/s, and a crystal accelerometer at frequencies between 400 and 5000 c/s; details of these pick-ups are given in Table I.

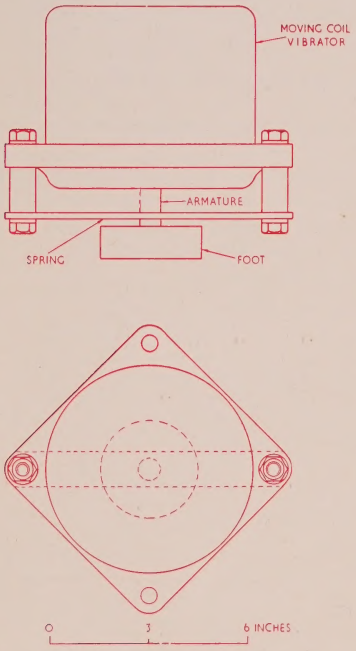

Fig. 2. Electro dynamic vibration generator.

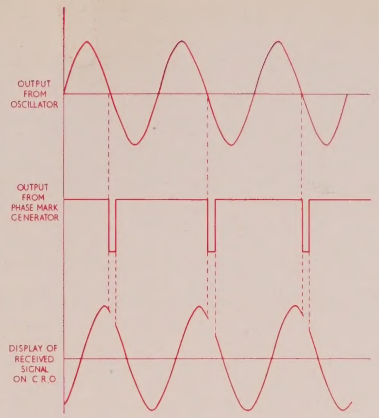

Fig. 3. Wave forms illustrating method used for indicating phase of received signal.

Vibrations within the frequency range of 5–24 kc/s are obtained as specific resonances of a ferro-electric ceramic transducer in the form of a hollow cylinder. The ceramic transducer is driven by the oscillator and by a tuned amplifier which has switched outputs, each tuned to one of the resonant frequencies of the transducer. The vibrations in the high-frequency range are detected by a hollow cylinder transducer which is identical with the generator; the specifications of the transducers are given in Table I. For convenience, the diaphragm of the receiving transducer has been tapered to a point to enable the shortest wavelengths, of about 2 in, to be located accurately.

In operation, the generator, which is either an electro-dynamic or a ceramic transducer, is placed on the road surface and the oscillator is tuned to the required frequency. The appropriate pick-up is moved progressively away from the generator and successive positions are found at which the vibrations are alternately in phase and in anti-phase with the fixed reference phase. These positions are indicated by the phase mark coinciding with a peak or a trough of the waveform display. The distances between successive positions are then equal to half wavelengths and, in practice, measurements are made over about four or more wavelengths in order to obtain a reliable average value.

In its application referred to in this article the apparatus is mounted in a Utility type vehicle, which also carries a 500 VA petrol generator to provide the electrical power.

PERFORMANCE OF THE APPARATUS

In the original apparatus, the receiver amplifier had a flat response over the range of frequencies 15 c/s to 350 kc/s. As a result, vibrations produced by traffic, usually below 40 c/s, were amplified, and formed a background noise. As the pick-up was moved away from the vibrator, the noise became of greater magnitude than the required signal and measurements could only be made when there was a lull in the passing traffic. The receiver amplifier was replaced by a Muirhead D-669-A Frequency Analyser, and there was an immediate improvement in the performance of the apparatus.

The frequency analyser, being tuned to the vibrator frequency, discriminates effectively against the traffic noise, and the distance to which workable signals can be received is almost double that achieved with the original amplifier.

The distances to which the surface vibrations are effectively propagated vary with the material and the frequency. On soil[2], the normal frequency range employed is 40 c/s to 400 c/s and, at frequencies below 100 c/s, distances of up to 60 or 80 ft can be achieved. At frequencies over 300 c/s, the distance is reduced to 20 ft or less; nevertheless, this covers a number of wavelengths (8–10) comparable with those measured at the low frequencies.

On concrete slabs, the frequency range extends from about 1000 c/s upwards; between 1000 and 3000 c/s, the limiting factor in the wave propagation is usually the longitudinal dimension of the slab. At the highest frequency, i.e. 24 kc/s, of the hollow cylindrical transducer given in Table I, effective propagation can be obtained over at least 15 wavelengths, each wavelength being of the order of 4 in. When determining the thickness of concrete slabs, it is necessary to work to even shorter wavelengths on slabs less than about 8 in thick. This involves the use of higher frequencies of about 38 and 57 kc/s, which are produced and detected by other matched pairs of ceramic transducers. Although these frequencies are outside the tuning range of the frequency analyser, it is found that adequate response is obtained on the 'flat' position.

ACKNOWLEDGEMENT

The work described in this article was carried out as part of the programme of the Road Research Board of the Department of Scientific and Industrial Research. The article is published by permission of the Director of Road Research.

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[1]JONES, R. A vibration method for measuring the thickness of concrete road slabs in situ. *Mag. Concr. Res.*, 1955, 7 (20), 97–102; Discussion, 8 (22), 50–2.

[2]JONES, R. Non-destructive testing of roads and structures. *Publ. Wks munic. Services Congr.*, 1956. *Final report*, 450–73; Discussion, 474–84

[3]JONES, R. In-situ measurement of the Dynamic Properties of Soil by Vibration Measurements. *Geotechnique*, Vol. 18, No. 1.

TABLE I — BRIEF SPECIFICATION OF APPARATUS

OSCILLATOR	Minimum frequency range: 30-60000 c/s Accuracy better than ± 1%
POWER AMPLIFIER	Output 50 watts in frequency range 30 c/s to 5000 c/s
OSCILLOSCOPE	Single beam with amplifier response to at least 60 kc/s and provision for coupling to modulator grid
ELECTRO-DYNAMIC VIBRATION GENERATOR	Modified Goodmans, Model 390A
GEOPHONE	Pye. Sensitivity about 2V/in/s
CRYSTAL ACCELEROMETER	Rochelle-salt bimorph.
CERAMIC TRANSDUCERS	Hollow cylinders of Casonic III (barium titanate) 6 in long × 1 in O.D. × $\frac{3}{4}$ in I.D. on $\frac{3}{16}$-in thick diaphragm, giving resonant frequencies of about 6, 10, 14 and 24 kc/s. Also solid prisms of Casonic on $\frac{1}{16}$-in thick diaphragms, 1 in square × 2 in, resonating at about 38 kc/s, and 1 in × 1 in × 1 in resonating at about 57 kc/s

A NEW MUIRHEAD TUNING FORK

In response to a demand for a standard frequency suitable for use with 400 c/s R.P.I. and control systems we can now offer a 400 c/s hermetically sealed fork complete with transistor drive amplifier. The unit measures only $2\frac{1}{2}$ in × 4 in × $5\frac{1}{4}$ in high and weighs under 2 lb. The amplifier draws only 10 mA at 9V d.c., and thus presents no serious supply problems. The a.c. output is 1V across a 3000 ohms load, and the long term frequency stability is better than 0·1%.

Optimum performance may be expected when the fork frequency is adjusted by us in conjunction with our drive circuit, but for customers wishing to design their own drive circuits we can supply the hermetically sealed fork as a separate unit. In these circumstances, however, we are unable to give performance figures.

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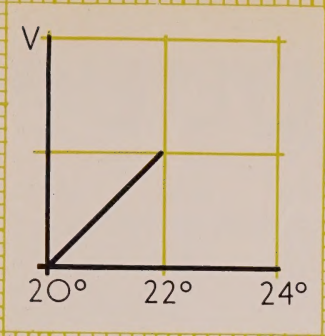

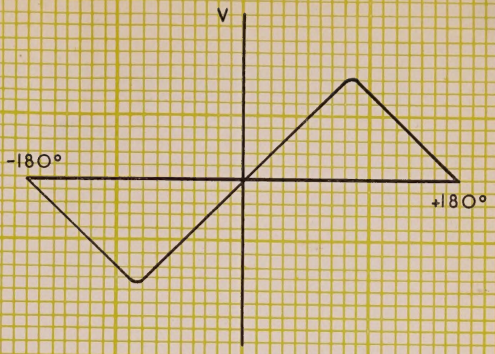

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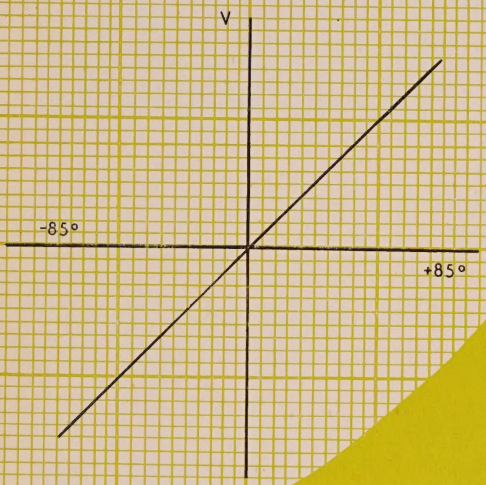

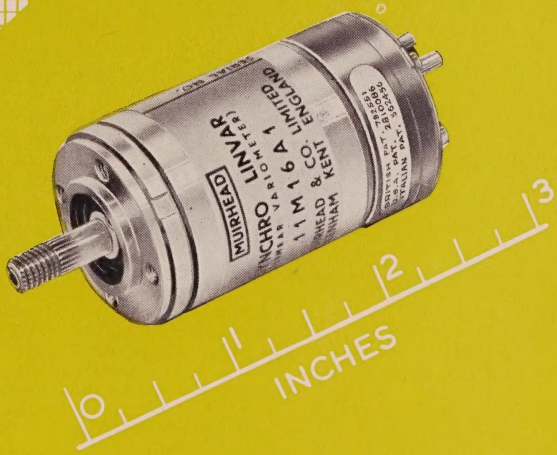

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VOLUME 13 NUMBER 1

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By A. Cooper, B.Sc. (Hons.), A.M.I.E.E.

THE FRONT COVER

The front cover of this issue depicts our new 115V, 400 c/s Synchro Linvar (linear variometer). This small size, light-weight element is housed in a standard BuOrd size 11 synchro frame. The patented design of rotor and stator laminations ensures a smooth variation of output voltage — devoid of fluctuations due to tooth ripple — extending for $\pm 85°$ from the zero output position, and the departure from linearity does not exceed $\pm\frac{1}{4}\%$ of maximum output voltage.

For full details write for Data Sheet 11M16A1.

INSTITUTION OF ELECTRICAL ENGINEERS — Faraday Lecture, 1958–59

'Automation' by H. D. Thomas, D.Sc., M.Sc., M.I.E.E., S.M.I.R.E.

This year the London lecture will be given at the Royal Festival Hall on Monday, 26th January 1959 at 6 p.m. Admission is free and tickets may be obtained from the Secretary, The Institution of Electrical Engineers, Savoy Place, London, W.C.2 from whom may also be obtained details of places in the provinces and dates at which the lecture will be repeated.

SYNCHROS

A new edition of Publication E-1000 having four additional chapters on synchros is being prepared and will be distributed to all recipients of the first edition and any other synchro or Magslip user on request.

Engineers who have appreciated the concise presentation of data on the synchro broadsheet will be pleased to learn that a similar publication on Magslips is about to be distributed to holders of Magslip data and to others on request.

We have now added to our range of synchros and servomotors a range of gearheads, in the size 11 frame, suitable for use with sizes 11, 10, and 08 servomotors. The gearheads have a non-corrodible steel case and are fitted with ball bearings throughout. Please write for data sheet G.11.

ERRATUM. Technique Vol. 12, No. 4.

In equation (7) page 28 the symbol ω should appear outside the square bracket.

BALANCING OF ROTATING MACHINERY USING ELECTRONIC AIDS

by H. L. Webb, B. Sc., A.M.I.E.E.*

Rotabalance electronic balancing equipment.

GENERAL

The Rotabalance Electronic Balancing Equipment (Fig. 1) manufactured by the British Thomson-Houston Co. Ltd., is designed to obtain by electronic means the information required for the balancing of rotating machinery. The equipment is ideally suited for use with machines running in their own bearings and consequently has a useful field in the final balancing of large machines. It has also proved of great value in investigations on machines where the vibration performance is below standard.

METHOD

The method employed involves the measurement of the amplitude or velocity of vibration on the bearing housings. At the same time the relative phase angles of the rotational frequency components of these vibrations are measured. It is usually found desirable to measure the vibrations in each of three mutually perpendicular directions on each of the bearings of a machine, which, in the case of a machine with several bearings, can result in a multiplicity of readings. However, with experience, some of these readings can be temporarily ignored, with resulting simplification.

APPARATUS

The information required is displayed on the front panel of the instrument in three ways. A meter is provided on which the total vibration velocity or amplitude may be read directly. At the same time a small oscilloscope displays a visual picture of the waveform. To assist in the examination, the time base may be synchronized to rotational speed using the voltage derived from the reference alternator, which is described later. If the vibration waveform contains appreciable non-rotational frequencies, the magnitude of the rotational fundamental cannot be read on the 'total' meter, but recourse has to be made to the dynamometer meter, which is also used in the measurement of phase angle.

A reference alternator, Muirhead Type E-28-C/1 3-in. Permanent Magnet Alternator Mk. II is coupled to the shaft of the machine under test by a light flexible drive. It is essential that there is no angular slip between the rotor of the reference alternator and that of the machine. A very simple and satisfactory drive can be made by utilizing two couplings of the type made for the remote operation of television controls, separated by a short length of $\frac{1}{4}$-in. diameter spindle.

*The British Thomson-Houston Co. Ltd

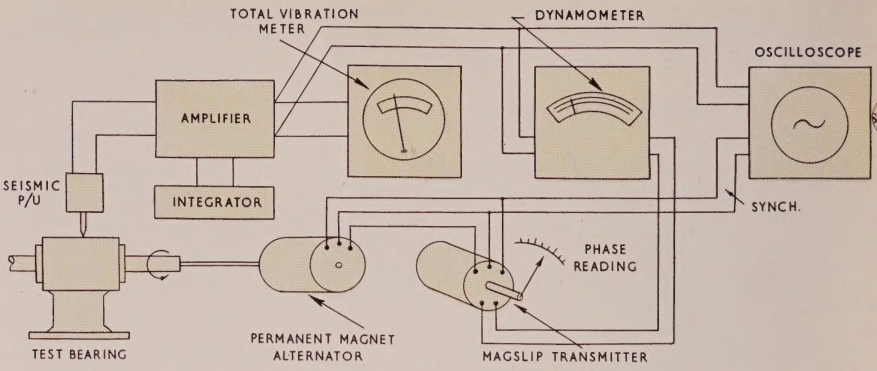


Fig. 1.

The reference alternator consists of a rotating permanent magnet inside a stationary wound field, and gives a 3-phase output of 50 volts at 3000 rev/min. The mounting arrangements for the alternator are not critical provided that it is rigid and that the flexible couplings are not required to take up undue misalinement.

A description of the pickup used is included later. Above its own natural frequency (about 10 c/s), the electrical output is proportional to vibration velocity. This voltage is amplified in a linear amplifier and fed to the output meter, the reading on which is therefore proportional to vibration velocity. It is useful on occasions, for instance where substantial vibrations at frequencies higher than rotational are present, to obtain the readings of vibration in terms of amplitude, and for this purpose an electronic integrating circuit may be switched in. The instrument will then emphasize the lower, or rotational, frequencies with respect to the higher, unwanted frequencies and make for easier reading.

For the measurement of phase angle and of fundamental rotational frequency vibration, use is made of a dynamometer instrument. One coil is energized directly from the amplifier described above. The other coil obtains its current from the single phase output of a Muirhead 2-in. Magslip Coincidence Transmitter, E-3-A/1, which in its turn is energized from the 3-phase stator output from the reference alternator E-28-C/1. The resulting deflexion of the pointer of the dynamometer instrument is proportional to the product of the coil currents at the same frequency and the cosine of the phase difference between them. It is evident that the phase of the vibration relative to the position of the reference alternator shaft can be ascertained by rotating the rotor of the Magslip E-3/A/1 till the deflexion of the pointer of the dynamometer is either at a maximum or at zero. It is found that the zero indication is more convenient on account of the more critical setting.

It is further evident that the maximum deflexion obtainable is proportional to the magnitude of the rotation component only of the vibration wave fed to the coil, since the current in the other coil is derived from the reference alternator at rotational frequency, and can be held at a fixed value. This feature proves very useful when it is desired to balance a machine in the presence of non-rotation frequency vibrations which are not caused by unbalance.

The vibration pickups employed with this equipment are of a seismic type. In these, the whole body of the pickup is mechanically coupled to the vibrating body, and so itself vibrates at the same amplitude and frequency. Inside the body is mounted a mass supported on flexible springs. When the body of the pickup is vibrated at a frequency above the natural frequency of this mass on its mounting, the mass remains sensibly stationary and relative movement between mass and case will result. This movement is translated into a voltage using a coil working in the gap of a permanent magnet, and electro-magnetic damping is provided by a copper ring working in the same magnetic circuit.

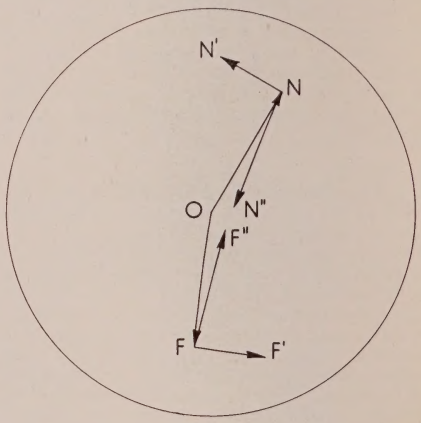


Fig. 2.

USING THE EQUIPMENT

In order to describe the method of use of the equipment, consideration of the tests on a 'single span' (i.e. a simple rotor mounted in two bearings at its ends) will be made. Initially, the readings of phase and magnitude of the vibrations in three mutually perpendicular directions (e.g. transverse, vertical and endwise) are taken on each of the two bearings. Examination of these readings will enable the operator to decide on a line of action. In general the larger values of vibration will be plotted as vectors and by examination a decision will be made as to the type of trial run. It may be decided to affix trial weights to give a 'static' (at the same angular position each end) or a 'couple' (mutually opposite angular position at the two ends) effect on the balance.

New readings will now be taken and the new vectors plotted on the same diagram as before. An arrow joining the end of the corresponding vectors will indicate the effect of the trial weights and the next move can be planned. To avoid confusion, it is usual to omit the actual vectors of all but the first vibration reading, simply plotting the effect of the weights.

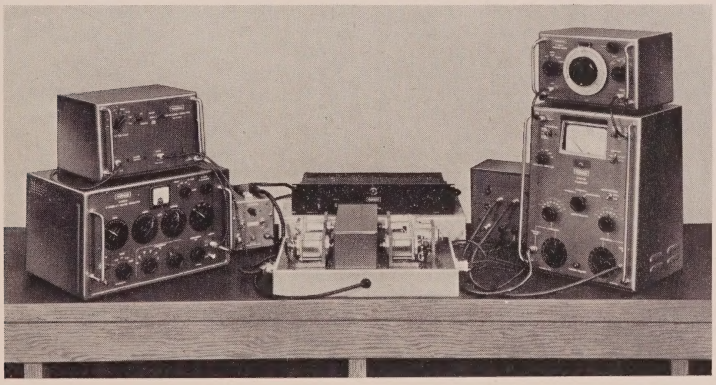
In Fig. 2, suppose ON is the vector representing the vibration velocity in a vertical direction on the bearing nearest the reference alternator, and OF the corresponding vibration velocity on the bearing farthest from the alternator. As these vectors are nearly on opposite sides of the origin, one would expect to choose a 'couple' trial. Suppose the corresponding trial vibration velocities are ON′ and OF′, the effect of the trial couple is shown by NN′ and FF′.

Examination of this diagram indicates that the trial vectors need to be moved anticlockwise by about 90° and increased by about 2 : 1. Modifying the weights in accordance with this might result in the vectors ON″ and OF″ which are now seen to be approaching each other both in amplitude and phase, and also approaching the origin. A slight modification could bring these even closer, and then probably a 'static' could be employed. During these trials, a watch should be kept on the other vibrations, to check that reduction of some does not result in an abnormal increase in others. With experience, the number of trial runs necessary to bring the final vectors sufficiently close to the origin can be made a minimum.

In general it may be expected that as many balancing planes as bearings will be required, and for a multi-bearing machine the process can be divided into stages. If however, sufficient balancing planes are not available, a great deal can often be done by intelligent application of the readings obtained, and the performance of most machines exhibiting symptoms of out-of-balance can be substantially improved.

THE MUIRHEAD TRANSFER FUNCTION ANALYSER

by A. Cooper, B.Sc. (Hons.), A.M.I.E.E.*



Methods of Testing Automatic Control Systems

During the development of feedback systems, which include Servomechanisms, the need often arises for experimental investigation of an interim design. Considerable mathematical analysis may have been performed and must be verified practically before large-scale production can be undertaken with safety. Further, production control may be improved by this means after the design has been finalized. A suitable testing procedure is therefore of great importance.

The feedback system receives an input signal of some kind (information) and uses it to produce a required output (result). In testing, the choice of a suitable input signal is consequently the first step to be taken. Actual signals will in general be random in nature, but the use of a random test signal results in an output difficult to assess mathematically. The information obtained is therefore of restricted use.

Similarly, other discontinuous inputs such as

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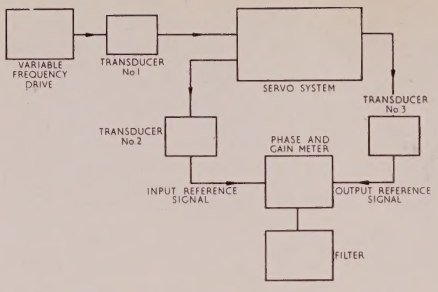

Fig. 1. Block diagram of frequency response measurement set-up.

step or ramp functions give limited information, not always susceptible to analytical treatment. Progress in design may then be laborious.

Advantages of Sinusoidal Method of Testing

Fortunately, the highly developed art of electrical communication provides an answer to the problem — the sine wave. By employing a continuous sinusoidal input and obtaining a resultant sinusoidal output (using suitable filtering if necessary) a variety of techniques and instruments becomes available. A complete plot of response with different frequencies then enables a mathematical relationship to be deduced fairly simply in terms familiar to engineers. This relationship, expressing the frequency response, is known as a transfer function.

Uses of Transfer Functions

The transfer function (G) may be divided into two parts, one of relative amplitude or gain, and one of phase. For steady state conditions the two parts define completely a linear system. They are also capable of being used to calculate the transient response. In certain cases it may be an advantage to measure the transfer functions of components, then synthesize a system. Design usually proceeds this way. Conversely, where it is impracticable to synthesize beforehand, as in the flight performance of a complete aircraft, the overall transfer function may be obtained experimentally, and the corresponding algebraic expression built-up from known units[1].

In communication engineering gain and phase measuring methods with sinusoids have been developed to high accuracy down to the limit of audio-frequency, about 20 c/s. Below this frequency new techniques are required and a Transfer Function Analyser has been specially designed to extend the range to 0·5 c/s. Before describing this in detail we shall consider the general requirements.

Test Equipment

In Fig. 1 is shown a block schematic of a Frequency Response measurement set-up which enables the gain and phase difference in a servo system to be obtained.

A variable frequency drive is provided by a sine-wave generator, which feeds the transducer No. 1. This transducer converts the generator output into a suitable form for energizing the servo system. The servo output is fed to transducer No. 3 which provides an electrical signal to a phase and gain meter. Transducer No. 2 connected to the input of the servo system, provides an input reference signal to the second channel of the phasemeter. These two signals are compared on the meter and the phase and gain plotted. When either input or output waveforms are distorted the filter is switched in to select the fundamental frequency and reject the other unwanted frequencies.

Of necessity the transducers will be different for the many different types of servo system, depending on whether it is electrical, mechanical, hydraulic, pneumatic, or otherwise. The variable frequency generator, the phase and gain meter, and the tunable filter can be made common to all measurements by suitable design and thus form the Muirhead equipment.

Muirhead Transfer Function Analyser

The three instruments which form the Transfer Function Analyser are shown in block form in Fig. 2. They are all electronic, since the wide frequency range encountered in testing different types of servo is most suitably catered for by this means.

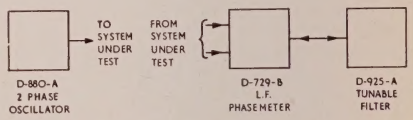

Fig. 2. Block diagram of Muirhead transfer function analyser.

The D-880 two-phase L.F. Decade Oscillator provides the variable frequency drive.

The D-729-B Phasemeter measures phase difference and gain (and voltage as well).

The D-925-A Tunable Filter is plugged in to the D-729-B Phasemeter to enable harmonics and other unwanted signals to be rejected.

A description of each instrument follows. Together they cover the frequency range of 0·5 c/s to 10 kc/s.

D-880-A 2-phase L.F. Decade Oscillator

This oscillator is the latest of a series of very successful Decade Oscillators and replaces the D-638, over which it has many advantages.

It has the wide frequency coverage of 0·01 c/s to 11 kc/s in five ranges, thus meeting test requirements for all but the slowest automatic control systems.

A power output of 10 volts across 600 Ω (160 milliwatts) is available via a 62 db continuously variable attenuator over the whole frequency range, from the 0° phase output.

[1] BURNS, R. A. and SAUNDERS, R. M. Analysis of Feedback Control Systems. McGraw-Hill: London and New York.

From the second output 90° (lagging) 10 volts maximum can be fed into a 10 000 Ω load simultaneously, and varied by a resistive potentiometer. Uses for this output will be described later.

The frequency accuracy is 0·2% from 5 c/s upwards, decreasing to approximately 2% from 0·1 to 0·01 c/s. Setting is by two precision decade resistor switches and one wire-wound continuously variable resistor from 0·1 c/s; with a separate decade switch giving 0·01 c/s steps from 0·01 c/s to 0·1 c/s.

A harmonic content from the 0° output of better than 0·5% and an output level constant to ±1 db throughout the entire frequency range are provided by a special level control circuit.

A low d.c. content in the direct coupled outputs assists in testing systems sensitive to d.c. level.

D-729-B L.F. Phasemeter

This has been described fully in previous issues of *Technique*[2]; modifications will however be mentioned.

Some have been made to enable the D-925 Tunable Filter to be employed; others to allow the D-669 or D-788 Frequency Analysers still to be used for frequency-selective measurements, whilst retaining the indication of the output meter of the Phasemeter.

D-925-A Tunable Filter

This twin-T rejection circuit, when inserted in the D-729-B Phasemeter output amplifier feedback circuit, provides an overall acceptance characteristic at its 'tune' frequency. A frequency coverage of 0·5 c/s to 10 kc/s in five ranges is provided giving with a Q of 20 2nd Harmonic (26 db) and 3rd Harmonic (30 db) rejection figures. Distorted waveforms, including demodulated waveforms in which the carrier predominates can therefore be dealt with by tuning to the required frequency.

The filter may be switched out when not required, but in use does not affect the phasemeter 'flat' gain by more than ±1 db.

In the phasemeter the two channel signals are compared and their vector sum obtained before the output amplifier. Hence, any phase shift in the filter has no effect either on phase or gain measurements. Mistuning will affect accuracy greatly only in cases of severe distortion (25% or more).

An Application of the Transfer Function Analyser

Consider first Fig. 3 which is a block diagram of a synchro feedback control system with one feedback loop. It is required to estimate its performance with regard to stability against self oscillation. Input reference signal r feeds an error detector (comparator). The error signal ϵ provides the actuating signal for the system elements of transfer function G. The system output is represented by the controlled variable c. This is arranged to be the feedback signal for correction purposes, and is applied to the error

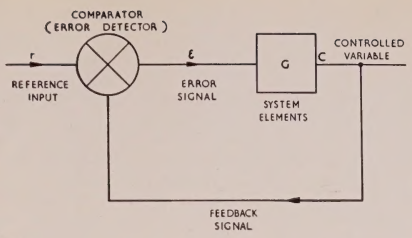

Fig. 3. Functional diagram of feedback control system.

detector so as to be subtracted from the reference input.

Hence we have:

$$\epsilon = r - c \quad \ldots\ldots .(1)$$

and

$$c = G\epsilon \quad \ldots\ldots .(2)$$

$$c = G(r - c) \quad \ldots\ldots .(3)$$

The quantity G is generally dependent upon frequency, and must be determined experimentally or theoretically in order to consider its effect upon the whole feedback system.

By suitable measurements we can obtain the feedback transfer function c/ϵ, the ratio of the output to error. One way is to break the loop at the input to the system elements and feed in a sinusoidal signal there, then measure c and ϵ with the feedback loop open. In certain cases the absence of feedback causes the system to drift or be otherwise unsuitable for testing. Then the signal ϵ is injected in series with the circuit and the loop left closed. Both methods give the same answer.

The servo system shown in Fig. 4 has been tested with the loop closed and a polar plot of phase and amplitude versus frequency is shown in Fig. 5.

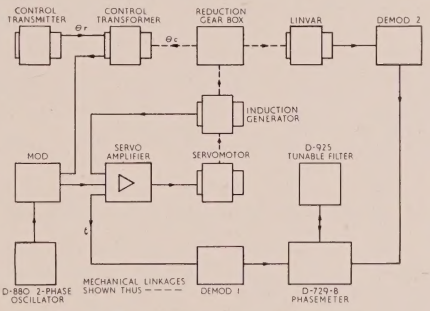

Fig. 4. Test set-up for servo system.

Details of Method

The control transformer output shaft position θc is required to maintain correspondence with the control transmitter shaft position θr. An error signal proportional to $(r-c)$ is fed to the servo amplifier, whose output energizes the

[2] COOPER, A. The D-729 Phasemeter and some Applications, *Technique*, Vol. 11, No. 4, October 1957, and Vol. 12, No. 1 January 1958.

servo motor. The motor drives the control transformer shaft via the reduction gearbox so as to minimize the error signal. Stabilizing of the system is provided by the induction generator output, an electrical signal applied in series with the control transformer error signal to the servo amplifier. The generator is also driven mechanically from the servo-motor shaft.

During testing, a sinusoidal signal was injected into the feedback system between the control transformer and the servo amplifier, the loop remaining closed. The D-880 2-phase oscillator supplied the signal via a modulator with suppressed carrier, the latter constituting transducer No. 1 of Fig. 1. An output signal proportional to c was taken from a Linvar and demodulator 2 (together comprising transducer No. 3) and fed to the D-729-B phasemeter. The error signal ϵ was taken from the input to the servo amplifier via demodulator No. 1 (transducer No. 2) to the phasemeter.

Tuning of the D-925 Filter to the test frequency was accomplished simply by setting the calibrated dial to the same frequency as that indicated by the oscillator and adjusting for maximum output on the phasemeter indicating meter. In Fig. 5 the amplitude has been plotted in decibels to increase the range.

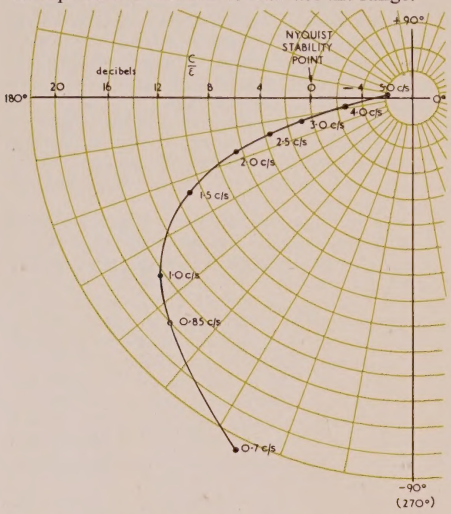

Fig. 5. Polar plot of feedback transfer function.

Note that the polar plot amplitude has been corrected for the difference between the amplifier gain when the motor is being driven (saturation condition) in the closed loop, and the increased gain available in the absence of an external exciting signal, (linear condition) the latter corresponding to the condition for stability examination. This difference can be obtained by measuring the ratio of the amplifier gains under the two conditions with the phasemeter.

Good agreement was obtained between the measured results and those expected. At low frequencies the phase tended to $-90°$ and the gain to a very high value. At approximately 4·8 c/s 180° phase change was reached with a gain of less than unity, 0·51 ($-5·6$ db). By increasing the gain to unity self-oscillation occurred at approximately the predicted frequency.

Advantages of the Transfer Function Analyser

(*a*) Direct readings of gain and angle between any two points in a system is possible, without reference back to the oscillator drive.

(*b*) Rejection of harmonics and carrier frequencies at least an octave away from the wanted signal is high.

(*c*) The tunable filter in conjunction with the phasemeter may be used to identify an unknown frequency by tuning it in on the output meter.

(*d*) The output meter has two different degrees of damping either of which may be used to enable minimum oscillation of the pointer to be combined with maximum speed of operation.

(*e*) Each unit can be used separately, e.g. where a driving frequency is provided by another source the phasemeter can be used with or without the tunable filter.

(*f*) The tunable filter also acts as a rejection filter on its own, of at least 80 db rejection. It may therefore be used with the Muirhead Wave and Frequency Analysers D-489, D-669 and D-788 to reject the fundamental of a low distortion wave and enable harmonics to be measured accurately. With an input of 100 volts to the filter whose output is connected to the input of the D-489 Muirhead Pametrada Wave Analyser it is possible to read to 0·001% (100 db down) on the second and higher harmonics.

(*g*) The oscillator may be used to supply a variable phase output into an impedance of 20 000 Ω or more over the whole frequency range. The ends of a 20 000 Ω potentiometer are connected between the high potential terminals of the two phases and an output taken between the slider and common low potential side.

Then we obtain:

Reference Phase	Variable Phase
0°	0 to 90° lagging
90° lagging	0 to 90° leading

Either fixed reference phase can be used to energize a system under test if the power available is sufficient, whilst the variable phase is applied to one phasemeter channel to reduce the output meter reading sufficiently to allow scale expansion to be used. Test phases of ±90° or near can be handled in this way.

Since the frequency range of the oscillator extends down to 0·01 c/s it may be employed with pen recorders to examine automatic control systems of slow dynamic response, where the D-729 Phasemeter is no longer suitable.

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The first commercially available range of electrical resistance heating equipment, designed to raise the temperature of copper conductors prior to extrusion of the insulation. Preheating ensures removal of moisture from the conductor surface, avoids breakage and shrinkage of the coating due to strains, ensures the correct degree of insulant adhesion to the conductor, and constant expansion conditions in the case of foamed insulants. Preheating equipments are therefore aids to higher extrusion speed and improved quality.

Special Features:

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Standard equipment of 1 KW, 4 KW and 7 KW.
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Portable and stationary instruments for the direct indication of wire tension. They serve to reduce breakages and stretching of the wire, ensure uniform outside diameters of reels, and enable exact adjustments in simultaneous multiple winding operations. Wire Tension Meters are an aid to higher winding speeds and the elimination of rejects.

Marketed in association with Fa. Schmidt, Germany.

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Simple rapid operation. Built-in tension meter.
Hardened chrome-plated measuring rollers.
Equipped with precision ball bearings.
Measuring ranges for 3 grams to 90 kg.

OPTICAL DIAMETER CONTROL

A true non-contacting diameter monitoring and control system for extruded sections, wires, and cables, using a unique light beam scanner. The gauge head may be installed immediately following the extruder. This system serves to avoid waste of insulating material, eliminates rejects due to undersize, frees the operator from continuous preoccupation with size control and ensures a uniform product.

Special Features:

The system is substantially independent of light intensity, relying instead on measurement of time.
Hence it is accurate, stable and tolerant to cable movement, fumes and parameter changes.
Extended measuring range 0—1¼ (32 mm).
Fully unitised for monitoring, recording and automatic control. Compatible with other ADDISON instrumentation in combined control stations.

SPARES & SE

NTATION FOR CABLE

TELCON CALLIPER GAUGE

A unique " feather-touch " diameter gauge for operation under water immediately following the extruder. Stainless steel callipers actuate via an ADDISON Magnetic Detector Unit the standard range of Indicator, Recorder and Control Units.
Marketed in association with TELCON Ltd.

Special Features:

Measuring pressure 0.3 ozs. (10 grams) approx.
Fully unitised for monitoring, recording, control and combination with other ADDISON Instrumentation.
Operation of calliper head within cooling trough, close to extruder without deformation of coating.
Measuring range up to 3½″ (90 mm) maximum.

CAPACITANCE MONITORS and CONTROLLERS

Non-contacting measurement and control of the average cable capacitance inside the cooling trough. Particularly applicable to the manufacture of wires and cables insulated with foamed materials, as well as for outer sheaths, and high frequency cables requiring constant capacitance, or the control of wall thickness.

Special Features:

Stainless steel 3 ft. (1 m) open trough electrode, designed for immersion into the cooling water.
Readings unaffected by the constituents of the water.
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Effective guard circuit. Ranges 0—3½ (90 mm).
Fully unitised for monitoring, recording, automatic control, and compatible with other ADDISON instrumentation in combined control stations.
Moderate price.

CONTACT DIAMETER CONTROL

The ADDISON Contact Gauge is the most widely used system for the accurate monitoring, recording and automatic control of the size of extruded wires and cables in the world. It serves to avoid waste of insulating material, eliminates rejects due to undersize, frees the operator from continuous preoccuation with size control and ensures a uniform product.

Special Features:

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Low cost—rapidly recovered by material saved.
Control of final diameter after shrinkage.
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Control Ranges: 0—3½ (90 mm). Unique facilities of:
(a) Single Plane Control.
(b) Dual Plane Control with Averaging Unit.
(c) Wall Thickness Control.
Latest improved model of standard gauge head is unique in using sapphire stylii, thereby eliminating bearings, ensuring extreme robustness and long wear up to the highest extrusion speeds.
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Special Features:

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Pictorial CRT display of cable cross section.
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Heads fully self-adjusting to different cable sizes.
Push button selection of multiple heads from central Monitor Station within 25 ft. (8 m).
Ranges 0—3½″ (90 mm)—Sensitivity ½% of wall thickness.
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Fully unitised for optional recording facilities, warning signals, and control: compatible with other ADDISON Instrumentation in combined control stations.

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Remote mounting electronic control unit.
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Compatible with other ADDISON Instrumentation in combined control stations.

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Marketed in association with the British Electrical Research Association and Hivolt Limited.

Special Features:

Compact—Unitised—Simple in operation.
Location of discharges revealed by form of display.
Range of accessories—moderate price.
Quantitative readings by use of unique calibrator circuit.
Narrow band amplifier ensures highest sensitivity, and greatest freedom from external interference.

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A complete range of Impulse Testing Equipments for voltages from 100 to 750 KV, comprising the impulse generator, measuring sphere gap, charging unit, remote control console equipped with 3-speed monitoring oscilliscope and recording camera.
This equipment is marketed in association with the British Electrical Research Association and Hivolt Ltd.

Special Features:

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Two column type of impulse generator incorporating integral capacity divider.
Direct reading KV-meter for monitoring stage voltage.
Voltage controlled sphere gaps.
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Reversible charging unit for impulses of either polarity.
Synchronised single sweep 3-speed oscilloscope.
Electro-mechanical earthing and interlock switches ensure a high degree of safety in operation.

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Unique instrumentation for the complete surveillance of vacuum impregnation. This provides for the simultaneous recording of the vital physical and electrical quantities throughout the drying and impregnating processes, thereby enabling close control of quality, saving of tank time, checking of the plant and operators, and affording improved end point determination.

Special Features:

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Moisture remnants—by insulation resistance measurements.
Vacuum—down to 0.005 mm. Hg.
Simultaneous recordings on linear paper chart.
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Temperature—from 0 —200° C.
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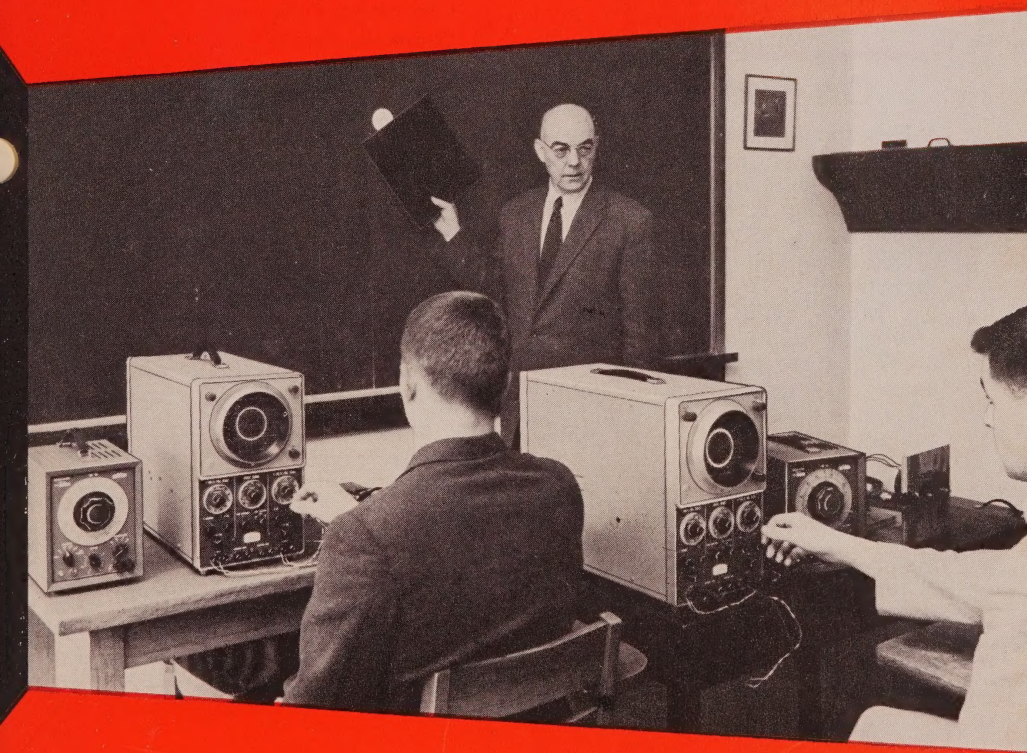
DU MONT Instrument Journal



DU MONT

INSTRUMENT DIVISION

DU MONT
Instrument
Journal

A PUBLICATION DEVOTED TO ELECTRONIC INSTRUMENTATION AND RELATED FIELDS. PROVIDING THE LATEST INFORMATION ON DEVELOPMENTS IN EQUIPMENT, APPLICATIONS AND TECHNIQUES. PERMISSION FOR REPRINTING ANY MATERIAL CONTAINED HEREIN MAY BE OBTAINED BY WRITING TO THE EDITOR AT THE ADDRESS BELOW.

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CLIFTON, N. J.

EDITOR - ARTHUR HOYT

CONSULTING EDITOR -
NEIL UPTEGROVE

On The Cover

Electronic circle drawing helps Dr. Morgan Upton maintain rigid controls over subjects in group psychological testing at Rutgers University (New Brunswick, N. J.). Chairman of the State University's psychology department, Dr. Upton utilizes Du Mont Type 401 Oscilloscopes (featuring identical X and Y amplifiers) in these tests which are being made to determine the relation of what man thinks he perceives to what has actually been presented to him. Dr. Upton is shown obscuring a white disc stimulus after it has been exposed to the subject for a fixed period of time; then the subject attempts to duplicate what he thinks is the size of the disc by expanding or contracting the electronic circle on the oscilloscope screen by a simple turn of a knob.

The winner of our IRE Show Oscilloscope Pattern Contest is announced and introduced on page 6. Five runners-up, who will receive *Du Mont Instrument Journal* binders, are also mentioned.

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A basic discourse on oscilloscope display recording with Polaroid-Land photographic materials. Techniques for the beginner and master are discussed, as well as detailed information on the process itself.

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The completion of an article introduced in Issue 5. It is a discussion of the relationship between the steady state and transient response of a linear channel. The article deals with such things as general and optimum requirements for the oscilloscope pulse channel, amplitude bandwidth, maximum rate of build up, delay distortion and phase bandwidth of linear channels.

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The winner of the contest held during the 1958 IRE Show is announced, and the use of such simulated 3-D scope patterns is explained.

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OSCILLOSCOPE PHOTOGRAPHY BY POLAROID-LAND PROCESS

by H. P. Mansberg
Manager, Applications Engineering
Allen B. Du Mont Laboratories, Inc.

A basic discourse on oscilloscope recording with Polaroid-Land photographic materials. Procedures for beginners are detailed, as well as pertinent information for the master. A discussion on writing rate parameters is given as well as the steps taken to obtain such figures. Primary types of Polaroid-Land photographic materials in their relation to end results is explained. To anyone working with or interested in such photography, the article will be of great informative value.

Part I

Although we have in the past published an extensive amount of information on conventional photorecording techniques, and many talks have been given on this subject, very little up-to-date information has so far been published on the specific subject of Polaroid-Land Oscilloscope Photography. Unquestionably the field of single frame photorecording of both stationary patterns and transients on the cathode-ray tube screen is now largely dominated by the Polaroid-Land photographic process. Improvements in both the quality and emulsion speed of Polaroid-Land materials have continued since the introduction of the Type 40 material just a few years ago. In fact, improvements have been so rapid that information which might have been published two years ago would probably be obsolete today.

The Polaroid-Land process (called a Diffusion-Transfer Reversal Process) is in reality a more conventional photographic process than the layman realizes (compared to techniques such as electrophotography, photosensitive glass and plastics, etc.). It is still basically a silver haloid process which is subject to some of the limitations and many of the advantages of conventional silver haloid photography. It also has a number of advantages not possessed by other photographic systems. The techniques which have been published, therefore, in the Du Mont *Oscillographer* and in our booklet *Techniques of Photo-Recording* still largely apply, but it is important to review some of these techniques, particularly stressing those factors which affect Polaroid-Land photography, and to present data and suggestions which we hope will be helpful to oscilloscope users.

Basically, the Polaroid-Land processing chemicals, in the pods attached to the film, are a thickened monobath mixture containing developing and silver halide solvent agents which cause silver reduction and fixing to proceed concurrently. The processing fluid is spread in a thin vis-

TABLE I

Relative Speeds of Polaroid Land Films for Oscilloscope Recording

Based on the Recording of Single Transients from P11 Phosphor Screens

Film Type	ASA Index (daylight)	Relative Speed* Normal	Prefogged
41, 31	100	1	10
42, 32	200	3	10
44	400	10	40
46, 46L	1000	10	30
Eastman Kodak** Tri-X Pan 35mm	250	60	—

*These numbers were arbitrarily assigned based on maximum photographic writing rates obtained using a Type 329-A Oscilloscope and Type 302 Camera with f/1.9 lens. Type 41 was assigned a value of 1 and the others followed by ratio of writing speeds obtained.

**Tri-X Pan film added to Table for comparison.

cous layer between sensitive and nonsensitive coated materials which are pressed together. Negative and positive images are formed concurrently, the negative on the sensitive layer and the positive on the nonsensitive layer. The reaction products of image formation in the viscous solution adhere to the negative so that when the positive is peeled off it contains only the transferred silver image which is permanent.

Those who have developed their own film, using conventional materials, may have observed that if the film was severely overexposed or exposed to light during development or before fixing, that an uncontrolled image reversal occurred. This effect sometimes called Solarization is one method of making direct positive images. The direct positive film for the black and white movies you take with your motion picture camera is also reversed during processing. The Polaroid-Land process however is unique in that it does not utilize a reversing exposure to produce a positive print, and that separate positive and negative images are concurrently produced.

Film Sensitivity

Although the effective sensitivity of the early Polaroid-Land materials to CRT traces was so low as to limit its usefulness to, almost entirely, recording stationary patterns, the ASA speed of the new materials such as Type 44 and 46L are as high or higher than those assigned to conventional high speed negative emulsions. However, the ASA speed index is not a suitable measure of the emulsion speed for transient oscilloscope recordings. A useful characteristic of Polaroid-Land film is that it responds very significantly to sensitization by prefogging, much more so than the ordinary negative film emulsions. More will be stated on this subject later. The availability of the new positive transparency Polaroid-Land material now makes it more likely than ever that crude sketches of oscilloscope waveforms in engineering reports and technical papers will be replaced by clear, reputable photorecordings. The ease with which prints can be made by dizaotype machines and the rapidity of preparing slides makes Oscilloscope Record cameras more useful than ever.

Available Polaroid-Land Films

The following paragraphs briefly describe the various Polaroid-Land films available and give some information about their characteristics. Table 1 also lists these films and provides a relative speed number which we have arbitrarily assigned to them

Feature

on the basis of their maximum photographic writing rate capability for single transients. For comparison, a relative speed number is shown for a conventional high speed photographic film emulsion. (Tri-X)

Types 31 and 41 Film

This film is Orthochromatic, having its highest sensitivity in the blue-green region. It is very suitable for the recording of stationary patterns and slow speed transients, particularly on the P11 screen. For steady state patterns it is certainly suitable for most phosphor screens. This film would not be recommended for photographing just the long persistence component of screens such as the P2, P7, P14, P19 and P25. That is, an orange or red filter should not be used on the oscilloscope with Types 31 or 41 film. It is the slowest of all of the Polaroid-Land materials, for single transient recording, but it responds most to sensitization by prefogging, giving about a tenfold increase in writing rate over the unsensitized condition.

Types 32 and 42 Film

This is a Panchromatic emulsion, which means it is sensitized to the yellow, orange, and red portions of the spectrum, as well as to the blue and green. Therefore it can be used to photograph the yellow or orange afterglow of long persistence phosphors, even when these cathode-ray tubes are covered with an orange or amber filter. An important characteristic of this film is that it has a greater gray scale range (it has a greater linear portion in the Density vs. Log Exposure curve) than Type 41 film. This gives one a better chance of recording the higher writing speed portions of a trace without over exposing very low writing portions of the same trace. For example, in recording a square wave with Type 41 film, a normal exposure for the flat top portion often results in the rise and fall portions of the wave form being invisible. The Type 42 film, on the other hand, is more likely to produce a usable exposure for the higher writing rate rise and fall portions near the threshold of the D vs. log E curve. This film is also faster than Type 41, but it responds less to prefogging (see table 1). It is less expensive than the very fast films to be described next, but it is more expensive than Type 31 and 41. It is the film most likely to be found at the local photographic supply store.

Type 44 Film

This is a very fast Panchromatic emulsion, making it very useful with all of the cathode-ray tube phosphors. It is faster than Type 41 and Type 42, and it responds to sensitization by prefogging—but to a lesser extent than Type 41. It is always the preferred Polaroid film for high speed transients except where positive transparencies are required for printing or projection. It also has a better gray scale range than Type 41, giving it similar advantages to Type 42 for obtaining adequate exposure for high and low writing rate portions of a trace.

Types 46 and 46L Film

This is a very fast Panchromatic positive transparency film which produces good transparencies for printing on diazotype print machines or projection. It has an extended gray scale, nominal contrast and wide exposure latitude, giving it similar advantages to Type 42 and Type 44 film. It provides approximately the same maximum photographic writing speed as Type 44 and responds well to prefogging. Note (Table 1) that although this film has an ASA speed rating of 1000, it does not produce higher single transient writing speeds than the Type 44.

This film requires two minutes for full development rather than 1 minute as required for the other materials. The emulsion is very sensitive to scratching so that after drying it must be dipped in a special solution

(*continued on page* 16)

OSCILLOSCOPE PATTERN CONTEST RESULTS

At the 1958 I.R.E. Show, Du Mont presented the opportunity to all visitors to participate in a contest of technical "know-how". A simulated three dimensional display was presented on a Du Mont Type 401 Oscilloscope, and it was the task of contestants to describe how the display was created. The one person most closely describing the exact method was awarded a Du Mont portable television set.

Mr. A. D. Baker, of Rochester, N. Y., was adjudged to be the recipient of the TV set by the judging board. A short background story on Mr. Baker is given below, followed by the exact solution by Du Mont and the report of the judging board, and a condensation of Mr. Baker's solution.

Other gentlemen deserving honorable mention for "coming close" are: Mr. John W. Dozier, Baltimore, Md.; Mr. Sam Zaslavsky, Bronx, N. Y.; Mr. C. F. Verra, Rockville, Md.; Mr. Eugene J. D'Amato, Erlton, N. J.; and Mr. Douglas MacMaster, North Granby, Connecticut.

Mr. A. D. Baker

Mr. A. D. Baker has been an employee of Eastman Kodak Company, Rochester, N. Y., for over eleven years. He is an electronic engineer, designing cathode-ray and sundry electronic instruments for the company.

During World War II Mr. Baker was engaged in national defense work at John Hopkins Applied Physics Laboratories in Silver Spring, Maryland. Prior to that he worked seven years as a radio and television theory instructor for what is now Central Technical Institute, of Kansas City, Missouri. After having worked in the latter establishment for four years, he set up and supervised the school's airline radio maintenance training program.

According to one of his associates, Mr. Baker is an ardent TV viewer. In fact, the circuit diagram submitted with his solution to the contest was conceived by him while watching a television program in a hotel room. Mr. Baker claims that the complete solution took him about 1½ hours. Our congratulations on his success.

Description of Du Mont Three Dimensional Display

The cathode-ray oscilloscope is most commonly considered to be a device for displaying information in the form of one or more variables as a function of time. Yet osciloscopes are frequently used to display the output of one transducer against the output of another, e.g., in plotting stress-strain curves, hysteresis loops, vectorcardiograms, etc. Sometimes a third variable is superimposed in the form of intensity modulation or blanking marks.

It has been shown, by a number of investigators, that simple electrical operations make it possible to represent functions of three variables in the form of an isometric, oblique projection or perspective picture on the

Application

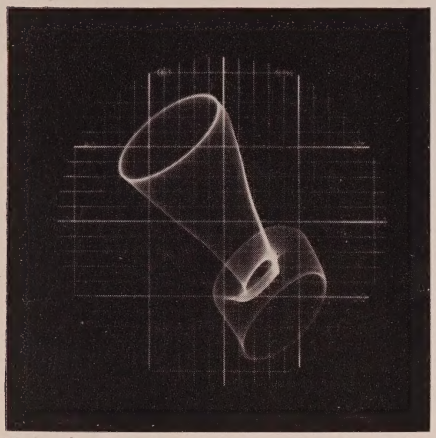


Figure 1. The simulated three-dimensional display pattern for the IRE contest.

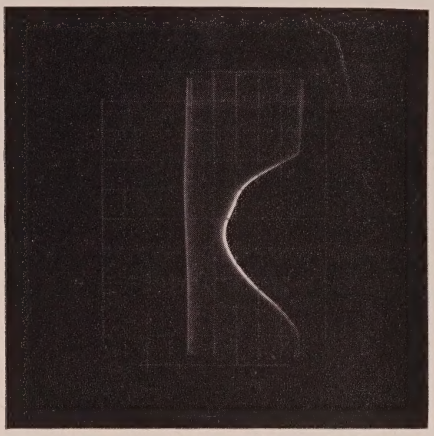


Figure 3. Modulated 10 kc signal.

cathode ray tube screen.[1-2-3] Such displays have applications in the fields of analog computers, radar, mechanical measurement, electromagnetic theory and others.

The object of the IRE display was to illustrate the usefulness of an oscilloscope, particularly one with equal gain -Y amplifiers, in plotting complex functions of three variables. For obvious reasons it was desirable also to present a pattern which had a recognizable shape and which would arouse interest.

Using techniques described in the reference the display pattern of Figure 1 was presented. The three signals were: a 10 KC sine wave, a 60 cps sawtooth voltage and a 60 cps sine wave. Referring to the block diagram of Figure 2, the output of a sinewave oscillator (10 KC) was modulated by a 60 cps sine wave obtained from a filament transformer. A very simple form of modulation was used (non-linear portion of diode characteristic) and the 10 KC carrier was partially clipped as shown in the modulation pattern of Figure 3. Careful inspection of the display pattern (Figure 1) will show a slight flattening at the neck of the cone and a

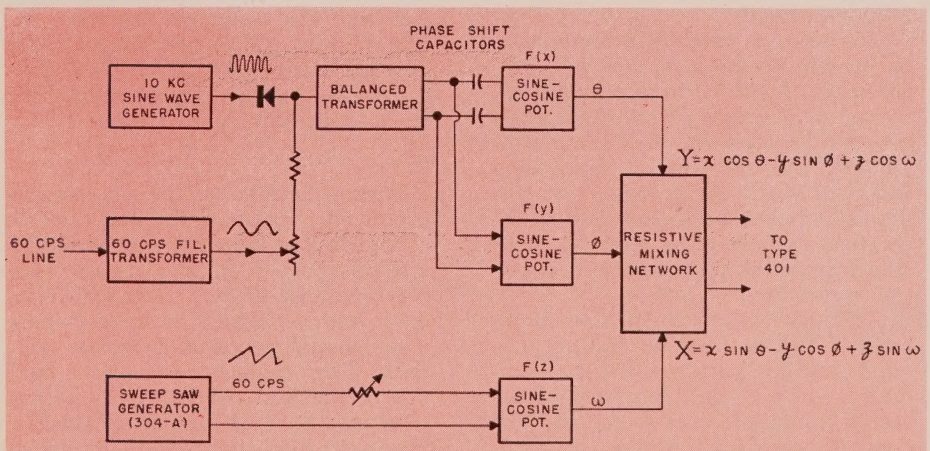


Figure 2. Block diagram of Du Mont method.

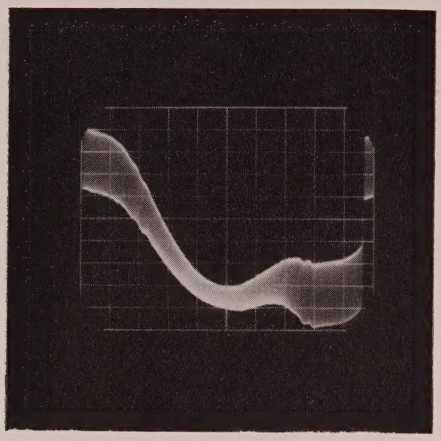


Figure 4. X-input to the Type 401 oscilloscope.

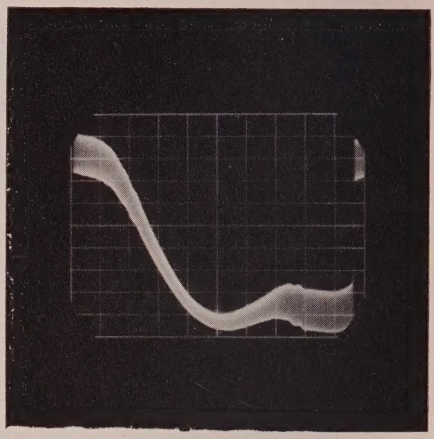


Figure 5. Y-input to the Type 401 oscilloscope.

corresponding bright edge all along that side of the cone, caused by this distortion. None of the contestants seemed to notice this effect as judged by the entries.

The modulated high frequency signal was then coupled through phase shifting capacitors to a sine-cosine potentiometer labeled F (x) and directly to another sine-cosine potentiometer labeled F (y). A 60 cps sawtooth waveform synchronized to the line frequency was fed to another sine-cosine potentiometer, F (z). The capacitors in combination with the resistance value of the sine-cosine potentiometers produced a phase shift of approximately 40° to give the elliptical shope.

To represent three coordinate electrical data or the x, y, and z coordinates of a point in three dimensional space, on a single plane, the signals may be resolved into X-Y plane projections by the use of sine-cosine functions of the angles made with this plane. Detailed discussions and mathematical derivations concerning these transformations may be found in the references cited.

Although any type of sine-cosine resolver can be used for the purpose (and similar patterns can be produced without such resolvers) sine-cosine potentiometers were used for convenience and relative independence of frequency. The use of three sine-cosine potentiometers makes it simple to rotate the entire figure into any quadrant of space and to view it from any "angle".

Finally a resistive mixing network was connected to the output of the resolvers to obtain the X and Y summations shown in Figure 2. The waveforms obtained at the X and Y inputs respectively, of the Type 401 are shown in Figure 4 and 5. These X and Y signals consist of 10 KC sine waves modulated by a 60 cycle sine wave to which a 60 cps sawtooth waveform is added. The actual appearance of the display depends on the portion of the 60 cps sine wave to which the sawtooth is synchronized and the setting of the three resolvers. For example, if the sawtooth is allowed to drift out of synchronization the pattern drifts through the stages shown in Figures 6 and 7.

Description of Winning Entry

Although none of the contestants produced explanations and circuit configurations identical with those described above a number showed that combinations of two sawtooth voltages and a higher frequency sine wave would produce a similar pattern. The earliest postmarked and one of the best detailed of these entries was that of Mr. A. D. Baker. Portions of his description and circuit diagrams are shown below:

Application

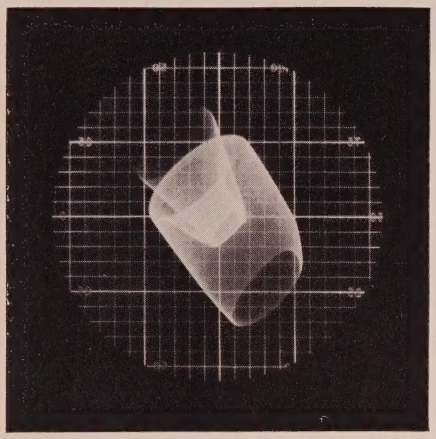


Figure 6. The display pattern of Figure 1 allowed to drift.

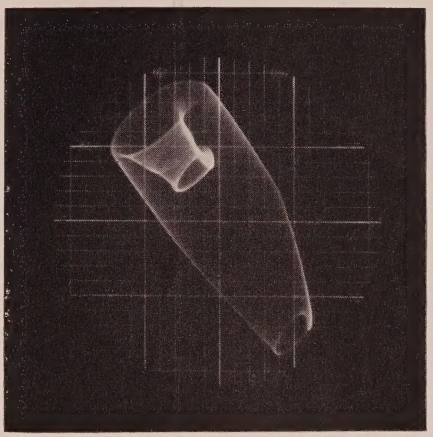


Figure 7. Another stage of the display pattern of Figure 1 if allowed to drift.

"The pattern appears to be that of a circular sweep as produced by two sine waves phase shifted 90° modulated approximately 33% by a sawtooth wave. The three dimensional effect may be produced by adding the modulating sawtooth component to the higher frequency modulated components. Phase shifting the modulating sawtooth component relative to the added sawtooth component will produce the effect of the ring around the apex of the cone. Except for the 90° phase shift between the wave components, identical signals are fed to both deflection amplifiers."

The block diagram submitted by Mr. Baker is shown in Figure 8.

(*continued on page* 15)

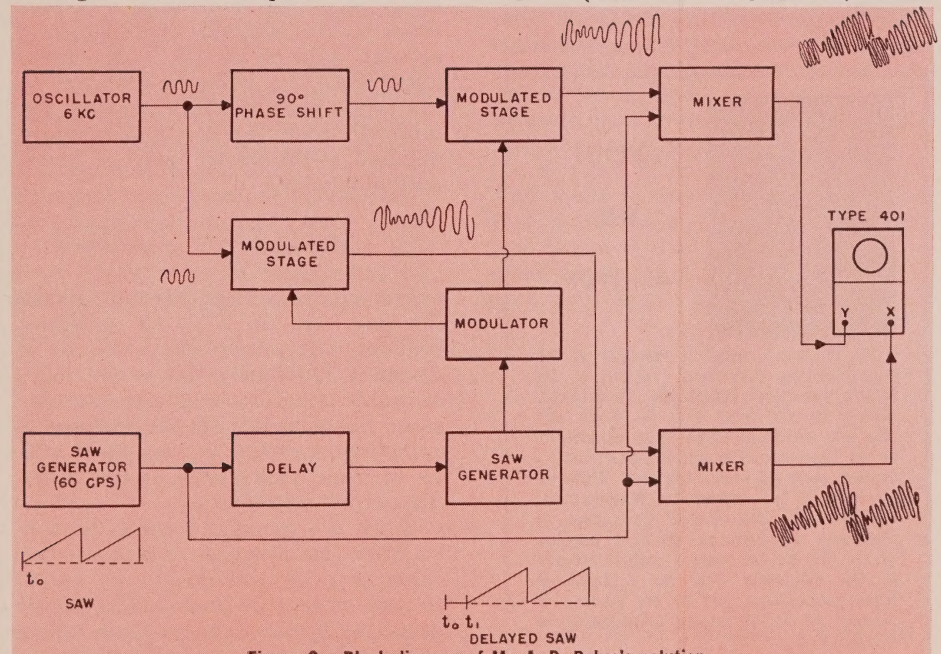


Figure 8. Block diagram of Mr. A. D. Baker's solution.

CONCERNING PULSE CHANNELS

Particularly Those in Oscilloscopes

by: William J. Judge
Section Manager: High-Frequency Instruments
Du Mont Instrument Division

Part II

Part I of this two-part article appears in Issue 5 of the Du Mont Instrument Journal.

D. Delay Distortion - Phase Bandwidth

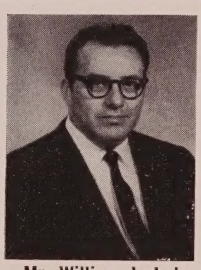
In the development of an expression for the maximum build-up rate in the previous section the sine components of the step-wave were assumed to be in the phase at $t = 0$; i.e., they were in time coincidence. As a practical matter the time of coincidence, say t_D, need not be zero, but any value. Now any channel consisting partially of reactances developes an apparent time delay by virtue of its phase-shift characteristics, although a time delay as such does not really exist. Time delay implies a finite velocity of propagation taken over some path length, such as in free space or transmission line propagation.

In a lumped circuit the idea of velocity is meaningless since length is not one of the circuit parameters. The lumped circuit will always develop an instantaneous response at its output coincidentally with the application across its input terminals of some driving force; the response will generally be rather small until a certain time, t_D, has elapsed, after which a normal build-up occurs. This virtual delay time, t_D, being a function of the phase shift characteristics of the lumped circuit, is more appropriately denoted as the phase delay — given mathematically

$$t_D = \frac{\phi(\omega)}{\omega} \qquad (11)$$

where $\phi(\omega)$ is the channel phase characteristic. If $\phi(\omega)$ is a linear function the phase delay will be a constant. Obviously this is the most desirable situation since with the constant phase delay all the frequency components of the driving force will be in time coincidence at the channel output terminals.

Since the primary interest here is confined to low-pass channels, the value of $\phi(\omega)$ will always be equal to zero at zero frequency. The phase delay, t_D, however, has a finite value at zero frequency and this may be



ABOUT THE AUTHOR

Mr. William J. Judge is manager of the high-frequency instrument section of Du Mont's Instrument Engineering Department. During his six years with Du Mont, Bill also had extensive engineering experience in the Television Transmitter Department—serving there as senior engineer. Although he holds a B.S. degree in Mathematics, his endeavors and interest have been in electronic development. He is a member of the IRE. He has written several articles in the electronic field for professional trade publications, and we are pleased to present his latest written contribution to the industry.

simply illustrated by considering the network of Figure 2. The phase-shift is given by the expression

$$\phi(\omega) = \arctan \omega RC$$

and the phase delay by

$$t_D = \frac{\phi(\omega)}{\omega} = \frac{\arctan \omega RC}{\omega}. \quad (12)$$

Although this latter expression becomes indeterminate at $\omega = 0$, its value is readily found via L'Hospital's rule, thus —

$$t_D = \lim_{\omega \to o} \frac{\phi(\omega)}{\omega}$$

$$= \lim_{\omega \to o} \frac{RC}{(1+\omega^2R^2C^2)} = RC.$$

Likewise ,as the frequency becomes undefined, equation (12) approaches zero as an upper limit since its numerator is bounded. Now all physical lumped channels exhibit the identical characteristic — i.e. — the phase delay is finite at zero and zero at undefined frequency. This is because the phase-shift is a function of the number of reactances in the circuit and so long as that number is finite, $\phi(\omega)$ is always bounded—hence the zero phase delay limit.

The significant point, therefore, is that in a physical lumped channel constant phase delay may not be realized over the whole energy spectrum. Of even more significance then, is the departure from constant phase delay, the relative phase delay, for a channel having relative phase delay different from zero no longer has its minimum build-up time equal to equation (10) — since all the frequency components of the driving force are not in time coincidence at the channel output terminals. The relative phase delay, thus, is the measure of delay distortion in a channel.

For minimum phase shift networks $\phi(\omega)$ is fixed by the prescribed attenuation characteristic R (ω), and if one is varied so is the other. These networks, furthermore, exhibit a reactance characteristic analogous to the concept of equal energy spectra for equal C described previously— i.e. — the area under the reactance characteristic is simply determined by the real part of the channel characteristic at zero frequency. Thus, if we again consider the network of Figure 2

$$\int_0^\infty \frac{X}{\omega} d\omega = -R_L \left[\arctan \omega RC\right]_o^\infty$$

$$= -\frac{\pi R_L}{2} \quad (13),$$

which also holds when any minimum phase non-dissipative coupling network N (Figure 3) is included. What equation (13) says is that the total area under the imaginary characteristic is determined only by the values assumed by the real characteristic at zero and undefined frequency—i.e.— the integral is independent of path. This leads to the obvious conclusion that if the major change in the real component is confined to a small frequency interval of the channel energy spectrum, then a pronounced change

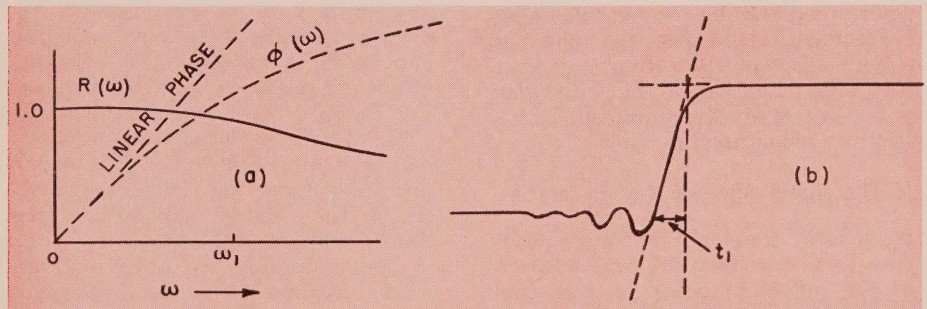


Figure 5. Steady state (a) and step (b) responses of an N-section cascade of constant resistance all-pass networks having a monotonic delay characteristic.

in phase shift occurs over the same interval; in the same way, if the real characteristic is gradually decreasing (curve 2, Figure 4) $\phi(\omega)$ describes a broad curve. The relative phase delay of a minimum phase shift channel having such a monotonically decreasing envelope shape will consequently contribute little in the way of delay distortion since a large portion of the phase area exists over that part of the energy spectrum where the real part is quite small.[5]

Certain low-pass channels, however, may consist of a large number of non-minimum phase shift networks in cascade (viz: a virtual delay line). It is quite common for these channels to exhibit severe departures from constant phase delay over portions of the spectrum where the attenuation is negligible. As an example, consider an n-section cascade of constant resistance all-pass networks having the characteristic shown in Figure 5a. At the frequency ω_1, the relative phase shift is $\frac{\pi}{2}$ and the attenuation is about 10%. (Theoretically, of course, an all-pass network is lossless. The finite Qs of the physical network reactances, nevertheless, account for a gradual attenuation.) The step response (Figure 5b) indicates a build-up time

$$t_1 = \frac{\pi}{\omega_1}$$ between steady-state levels

and a preceding oscillation of frequency f_1. Thus, the build-up time is determined here by the relative delay characteristic and not the channel energy spectrum. We may say that this channel has a *phase bandwidth* of f_1 — certainly the amplitude bandwidth is much greater.

The significance of the $\frac{\pi}{2}$ relative phase shift frequency becomes intuitive if one considers the time position of the inflection point of any sine component, of the step-wave, occurring at a frequency greater than f_1. These components, having a relative phase shift greater than $-\frac{\pi}{2}$, do not contribute to a faster build-up, but rather account for the preswings.

Summarizing, delay distortion has the following deleterious effects on the channel response:

a. introduces an assymetrical component into the transient response which is subjectively poor (Figure 5b)
b. limits the speed with which the channel can transmit information (the phase bandwidth) and consequently reduces the maximum rate of build-up.

In general, the phase bandwidth of pulse channels has not received the engineering consideration it deserves, although its presence has been recognized inadvertently; namely, through manifestation of longer build-up time than calculated (or measured) from the amplitude response, and via transient assymetry. A well designed channel will minimize the assymetry through linearization of $\phi(\omega)$ to some compromise frequency.

E. Optimizing the Channel Characteristic

A linear channel will be distortionless only if its input and output waveforms are identical. Since the input waveform may be analyzed into a spectrum of sinusoidal terms, the channel must not discriminate against any term, i. e., it shall not be frequency selective. Frequency selection can occur in two ways — effecting either the relative amplitude or phase (or both) of any term in the waveform spectrum. Physical channels, of course, exhibit both types of selection and the engineering problem is to optimize the channel capabilities consistent with the application.

Conventionally, the pulse, (or vertical) channel of an oscilloscope is expected to exhibit distortion only in

5. Bode, H. W., Network Analysis & Feedback Amplifier Design, pp 286.

regard to build-up time (Fig. 1b). This imposes definite restrictions on the channel characteristics which have been generally set down in section A (Issue 5, page 3) and it seems desirable at this time to elaborate a bit more on those three requirements. The necessity for constant phase delay should now be obvious in view of the discussion contained in the previous section. As a practical matter, the phase characteristic will be linearized to some compromise frequency such that the economics of the situation are satisfied.

For example, in a channel consisting only of minimum phase networks the amplitude and phase characteristics are interdependent and the best possible compromise must be realized. When non-minimum phase networks are present*, a much simpler situation exists since those networks permit adjustment of the phase without effecting the amplitude characteristic.

The other two requirements concern the transfer modulus and merely state that the channel shall exhibit a monotonic attenuation characteristic (drooling roll-off). Convention appears to be completely in charge here, but not without virtue. Such a characteristic — a. permits derivation of a step response having a single pronounced inflection point (Fig. 1C) which is subjectively good. b. simplifies the analysis of complex waveforms whose spectra lie mostly within the channel transfer modulus. c. extends the high frequency usefulness of the channel well past the half power frequency. d. develops a near constant phase delay and simplifies the correction problem. The principle objections to the monotonic shape are its inability to realize the minimum 10-90% build-up time within the confines of the channel capabilities, and the shape itself (for sinusoidal or narrow band† measurements a flat response is more desirable).

*Usually in the form of an all-pass virtual delay line.

†Such as an amplitude modulated carrier.

6. Kenney, J. F. *Mathematics of Statistics*

The limiting envelope shapes for a family of monotonic responses having identical energy spectra are illustrated by Fig. 4, where curve #2 is the uncompensated RC case. The corresponding step responses (due to R (ω) only — the phase delay is assumed to be constant) indicate somewhat different build-up paths except at the half amplitude points where the maximum rate of build-up is encountered. Of particular significance is the difference in the so called rise time†† which is $0.8\pi/\omega$, for the flat-top versus $1.7\pi/\omega$, for curve #2. Thus, envelope shapes belonging to the same family can exhibit rise times which differ by more than two to one.

The problem, therefore, is to obtain an envelope shape having the same finite bandwidth as those in Fig. 4 and a minimized rise time consistent with the distortion requirements. Obviously, neither of the responses of Fig. 4 are satisfactory — one suffers from ringing, the other from smear. Now since an indefinite number of monotonic envelope shapes may exist, for a given energy spectrum, it follows that their corresponding step responses may take on any form intermediate to those of Figure 4. Intuitively, then, there must exist a response which exhibits the fastest rise time without preswing and overswing, and likewise a response with a minute amount of both and still faster rise time. The latter case would appear to be more desirable in spite of Fig. 1b since conventionally some overswing is always specified and the rise time advantage is important. The monotonic shapes responsible for the aforementioned step responses are fairly well known as the Gaussian and "Cosine-Squared" curves respectively. Let us consider both in detail.

The normal curve of De Moirve is represented by the expression[6]

$$Y = \exp(-h^2 x^2) \qquad (14)$$

††Build-up time measured between 10% & 90% points of transition.

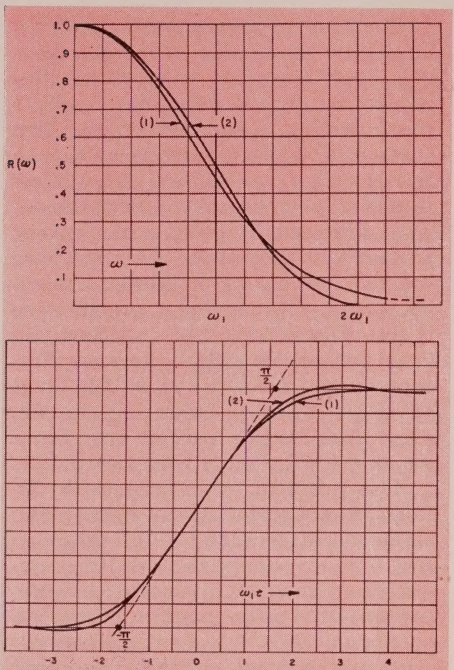


Figure 6. Steady state (a) and step (b) responses of two channels having equal energy spectra, and respectively — Gaussian (1) and Cosine-Squared (2) envelope shapes.

and the area $\int_0^\infty ydx$

is found by not so simple integration[7]

$$A = \frac{\sqrt{\pi}}{2h} \qquad (15)$$

The Gaussian curve is a special case thereof and exists for a certain value of h. It may not be realized physically but is approximated closely in an n-stage constant current RC amplifier when n is large (ten or more). As the number of stages is passed to the upper limit, the real part of the transfer characteristic is given by

$$R(\omega) = \exp(-\omega^2/k^2\omega_0^2) \qquad (16)$$

where

$k = 1.2$

ω_0 = half power frequency.

Equation (16) may be derived without too much difficulty[8] and is left as an exercise for the student. Consider a Gaussian curve belonging to the family of Fig. 4 and thus having an area

$$A = \int_0^\infty R(\omega)\, d\omega = \frac{\pi}{2}.$$

It follows, then, from (15) and (16) that the half power frequency

$$\omega_0 = \frac{\sqrt{\pi}}{K} = 1.48 = .94\omega_1.$$

The curve and its corresponding step response is illustrated by Figure 6.

Significantly, a rise time of $\frac{1.03\pi}{\omega_1}$

is obtained without preswing and overswing.

A further improvement over Gaussian response is obtained via the Cosine-Squared curve (Fig. 6) at the expense of slightly less than 2% preswing and overswing. This shape, which may be considered the optimum for an oscilloscope pulse channel, exhibits the form of one complete cycle of a cosine curve and has as it equation

$$R(\omega) = \tfrac{1}{2}\left[1 + \cos\frac{\pi\omega}{2\omega_1}\right]. \qquad (17)$$

The step response has a rise time of $\frac{.92\pi}{\omega_1}$, a speed-up of 1.12 over the Gaussian although its conventional bandwidth (3DB frequency) shows an improvement of only 6%. The Cosine-Squared curve, like the Gaussian, is non-physical but may likewise be closely approximated in physical systems. It is an easy curve to work with since its half amplitude point coincides with that of a flat-top and the 3DB and 6DB points are nearly reciprocally related.

The choice of Gaussian versus Co-

7. Wilson, E. B. *Advanced Calculus*
8. Cherry, C. *Pulses and Transients in Communications Circuits*

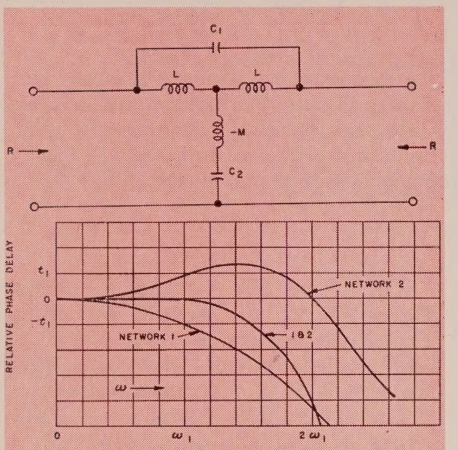


Figure 7. (a) The constant resistance all-pass filter network, (b) relative delay of two networks having the same driving resistance but different parameters, and relative delay of those two networks in cascade.

sine-Squared curves will depend upon the type of physical channel involved. Channels consisting simply of minimum-phase networks will, in general, exhibit a constant phase delay with a Gaussian response whereas the Cosine-Squared develops a lagging phase error. Consequently, little or no improvement in rise time is obtained since the requisite preswing cannot be realized and the step response is not skew-symmetrical. For those channels utilizing partially non-minimum phase networks, the Cosine-Squared response appears to be the better choice since its phase error may be corrected; i. e., the phase bandwidth of the channel is extended high enough in frequency such that a skew-symmetrical step response is developed and the superior rise time of the Cosine-Squared shape obtained.

The non-minimum phase networks are generally present in the form of a virtual delay line consisting of constant resistance all-pass filter sections. Networks of this type (Fig. 7) can have negligible attenuation over the useful part of the channel energy spectrum and yet develop a wide variety of relative phase delay characteristics dependent on the choice of network parameters[9]. By appropriate cascading of networks having the same driving resistance but dissimilar relative phase delays, the phase bandwidth of the line may be extended almost indefinitely. Furthermore, relative phase delay errors developed in that part of the channel consisting of minimum phase networks may be corrected to some compromise frequency by purposely introducing an opposite error in the virtual delay line. This principle is simply demonstrated with two networks by Figure 7. where, significantly, the phase bandwidth of a channel consisting of network #1 only is improved 50% by the addition of network #2.

9. Judge, W. J. "Simplifying Phase Equalizer Design." *Electronic Industries and Tele-Tech,* (May 1958)

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Kenney, J. F. **Mathematics of Statistics.** New York: D. Van Nostrand Co., 1939
Wilson, E. B. **Advanced Calculus.** Boston: Ginn and Co., 1911

"Contest" (continued from page 9)

We congratulate Mr. Baker and Du Mont Television set.

wish him enjoyment in the use of his

Judging Board

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OSCILLOSCOPE PHOTOGRAPHY BY POLAROID-LAND PROCESS

(*continued from page* 5)

to harden it. This is available in a very convenient plastic container called a "Dippit" which only requires a few seconds to use.

The transparency should be viewed by means of a strong uniformly diffused source of white light. For projection in standard 3¼ x 4 inch projectors, plastic frames are available, such that the positive transparency can be prepared for projection, within a few seconds, by snapping into one of these frames. A word of caution regarding projection is in order. When the transparency is mounted in these plastic frames it does not have the protection usually provided by standard lantern slides with cover glass. Therefore projectors with inadequate cooling, or very long projection exposure times will cause the film to buckle. For permanent lantern slides the positive transparency may be bound between standard 3¼" x 4" lantern slide cover glasses.

Which Film to Use in Du Mont Oscilloscope Cameras

The Type 302 Camera — Uses Types 41, 42, 44, 46 and 46L film. The Type 46 film provides 2¼" x 2¼" transparencies while the 46L provides 3¼" x 4" transparencies.

The Type 339 Camera — Uses Types 31 and 32 film.

Part II of the article, discussing actual photographing techniques, the determination of photographic writing rates, presensitizing films and other techniques, will appear in issue 7 of the *Du Mont Instrument Journal.*

The Engineer Speaks

Dear Sir:

"The writer was especially interested in the article entitled 'Oscilloscopes Invade the Automotive Industry' (Issue 3, page 12) because of a long-standing conviction that modern technology and engineering could make significant contributions to the automotive service field, particularly in diagnosing faulty operation, performance testing and evaluation of mechanical condition, by providing equipment for doing the job better, quicker, in quantitative terms and preferably in the form of graphical recordings. Your EnginScope is an outstanding example of this general type of equipment. However, there are several other automotive testing jobs for which currently available equipment is relatively inadequate. For example, there is a need for a good, quick-acting recording chassis dynamometer; a cylinder pressure recorder that will produce a record, in one minute, of the variations of pressure (and vacuum), at cranking speeds, within each cylinder of a 4-, 6- or 8-cylinder engine; a good reliable meter for indicating instantaneous values of fuel consumption rates in miles per gallon at various engine speeds and loads, etc., etc. For some time the writer has been working with a local automotive service engineering firm interested in using such equipment for quickly and accurately evaluating the condition and performance of used cars and fleet vehicles. It has turned out to be a long, uphill pull because suitable devices just don't seem to be available. Perhaps some of your readers are familiar with equipment of components adaptable for this purpose. If so, any relevant information or suggestions would be very gratefully received. There might even be enough available to constitute material for a future article on this subject in your interesting Journal!"

Sincerely yours,
W. Julian King
Professor of Engineering
University of California

Editor's Note: We're ready — send us the stuff.

TECHNIQUE
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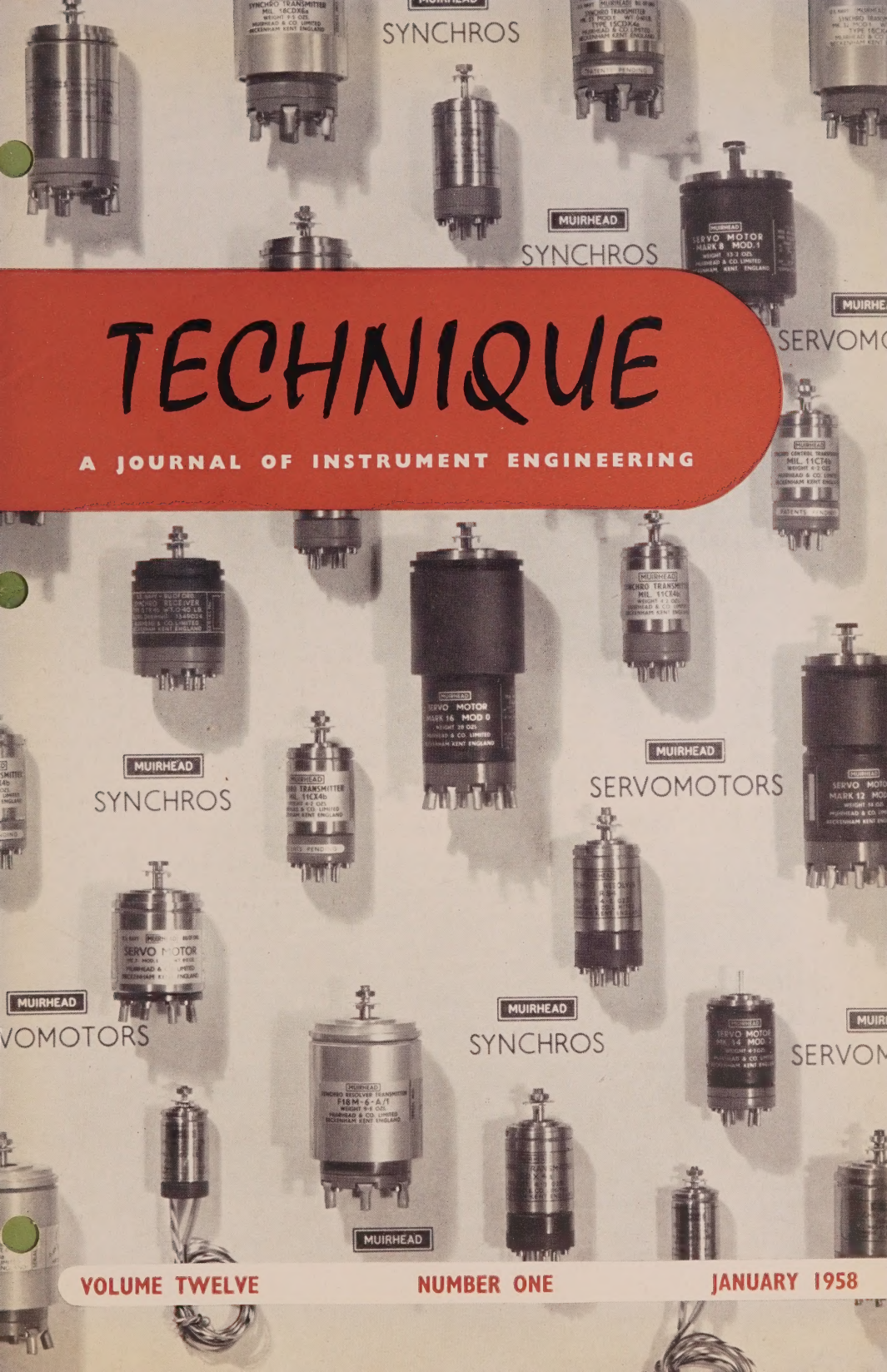

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MUIRHEAD SYNCHROS

The cover illustration of this issue is copied from the cover of a new Muirhead Synchro Broad Sheet. This latest publication, giving quick reference to the principal characteristics of over a hundred types of Muirhead Synchros and Servomotors now in current production, is of special interest to control system designers and manufacturers. Copies are available on request.

New additions to the Muirhead range of Synchros since the publication of the October 1957 issue of Technique include:

A range of size 23 Synchros, a size 10 Servomotor, a size 15 Feedback Resolver and a size 23 Sweep Resolver with feedback windings.

Technical information on the above Synchros will be forwarded on request.

SYNCHROS. 11CX4b–11CX4a, 11CT4b–11CT4a, 26V 11CT4b–26V 11CT4a.

On numerous occasions we have been asked to explain the origin of the 11CX4b, 11CT4b and 26V 11CT4b and the points of difference between them and the instruments bearing the 'a' suffix. The 11CX4a, 11CT4a and 26V 11CT4a were developed originally to U.S. Navy Bureau of Ordnance drawings and featured an aluminium alloy body 1·235″ long measured from the front of the major mounting spigot, and a terminal moulding 0·537″ long. Subsequent experience has resulted in a lengthening of the body and shortening of the terminal moulding whilst maintaining the same overall length. This modification gave increased winding space and thereby reduced the risk of electrical failure. A further development was the replacement of aluminium alloy by stainless steel as the body material, this resulted in improved low temperature accuracy since the thermal expansion coefficients of the laminations and housing were made compatible. The U.S. Navy Bureau of Ordnance have allocated the suffix (b) to these improved types, and we have adopted it where applicable. However some manufacturers are still supplying size 11 synchros having the (b) dimensions but carrying the (a) suffix.

The (a) and (b) versions are completely interchangeable both electrically and mechanically.

FORTY-SECOND PHYSICAL SOCIETY EXHIBITION

The 42nd Exhibition of Scientific Instruments and Apparatus promoted by the Physical Society Council will be held in the Old and New Halls of the Royal Horticultural Society, Westminster, London from Monday, 24th March to Thursday, 27th March 1958.

As in the past we shall be exhibiting our newest instruments and components which comprise the following items:

D-788-B Low-frequency Analyser — includes a synchronous motor drive for the frequency dial thus enabling an input frequency spectrum to be automatically scanned over a single frequency range of the instrument. The synchronous drive makes it possible for two or more analysers to be used synchronously. Manual control is also provided.

D-729-B Phasemeter

This instrument measures the phase angle (0–360°) and level difference (up to 70 dB) between two substantially sinusoidal voltages in the frequency range 0·25 c/s to 10 000 c/s while imposing no appreciable load on the voltage sources. In operation, the phasemeter measures the sum of the two voltage vectors after they have been adjusted to equality. Under this condition, the vector sum is a function of the phase angle only. The instrument is ideal for measuring the phase-gain characteristics of active and passive networks, and because of its low-frequency range, it is eminently suitable for determining the transfer functions of servo systems.

D-858 Low Impedance Attachment for D-728 Impedance Angle Meter

This instrument will extend the impedance range of the D-728 Impedance Angle Meter from the existing lower limit of 3 ohms down to 1 milliohm.

D-397 Universal Bridge — a self-contained, mains-operated instrument for measurement of resistance, capacitance, dissipation factor, inductance and Q-factor.

In addition to the built in 1000 c/s oscillator and tuned detector an electronic automatic earth balancing device ensures almost complete immunity from errors due to the earth capacitance of the bridge.

D-901 Facsimile Transmitter. D-900 Facsimile Recorder

These machines provide completely automatic transmission of commercial, industrial and scientific information and data over the normal telephone system. The transmitter will accept all forms of printed matter, typescript, hand-written messages, drawings and sketches which are reproduced by the recorder as error-free facsimile copies of the originals.

Synchros and Servomotors

The Muirhead range of synchros and servomotors now covers more than 60 different types in frame sizes 08, 11, 15, 18 and 23. Outline dimensions of all instruments conform to N.A.T.O., R.A.E. and U.S. military standards. Direct equivalents are available for nearly all U.S. military approved synchros.

THE USE OF MAGSLIPS AND RELATED DEVICES IN THE FIELD OF FLIGHT SIMULATION

By D. R. Jarman, B.Sc.(Eng)*

THE FLIGHT SIMULATOR

As the cost of flying a modern aircraft rises with the increase in the amount and complexity of the equipment carried, so the problems of training aircrews become more acute. To train a pilot to fly, and to maintain his efficiency by means of regular 'refresher' courses, is an extremely costly business. It is for this reason that the Flight Simulator has come into such prominence in recent years. The training of aircrews in such a device costs a fraction of the amount involved in flying an aircraft and is completely safe.

Basically, a Flight Simulator is a reproduction of the cockpit of an aircraft, containing all the instruments and equipment which are carried in flight. By the use of analogue computers, the equations of motion of the flight are solved, and the answers are presented to the instruments in the cabin in such a way that the simulator appears to be flying. Information is fed into the various engine and flight computers from the throttle controls, the control column and the rudder pedals. This is obviously a much simplified picture, but it serves to illustrate the principle.

Another important part of the simulator is known as 'Radio Aids', and it is with this section that this article is particularly concerned. Before, however, discussing this more fully, a brief mention will be made of the component parts of the analogue computers themselves.

THE STANDARD SERVO UNIT

Both a.c. and d.c. carriers have been used to transmit information in analogue computers. There are advantages and disadvantages in both systems, but it is not the purpose of this article to discuss them. A.C. has been used in the Flight Simulator under discussion, and suffice it to say that the stability and lack of drift of the computing amplifiers, and the ease with which the signal level and phase (this refers to the phase with respect to a reference

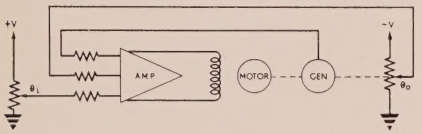
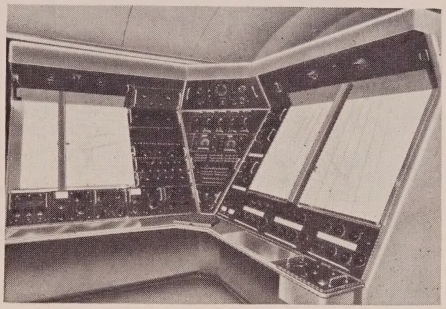


Fig. 1

and is either /0° or /180°) can be changed by means of transformers, make this quite an attractive system.



The servo unit is an electro-mechanical device and consists of an amplifier and a motor, which drives either a potentiometer or some form of Magslip. A simple position control servo is illustrated diagrammatically in figure 1.

The motor also drives a tachometer generator, which provides damping in the system. The input voltage, the tachometer generator feedback, and the output voltage are all summed on the grid of the amplifier by means of a parallel resistance network. The weightings of the various inputs are controlled by this resistance network, and it follows that the correct degree of damping and the overall feedback can be readily adjusted.

Integration can be performed quite simply with such a unit by removing the output connexion.

The device will then run at a speed proportional to the input, and will perform the function of integration with respect to time. Any constant can be set into the system and the rate of integration can be controlled by means of the generator feedback.

A wide variety of functions can be generated by the expedient of contouring the potentiometer winding. The design of such a potentiometer is based on making the width of the winding at any point, proportional to the slope of the function at that point.

Sine and cosine functions can be generated in the manner just described, but a more accurate method involves the use of a Magslip resolver. Such a device can be included in the servo unit in place of or as well as a potentiometer. The use of Magslip resolvers, transmitters, follow-through transmitters, etc., will be described in the next section.

RADIO AIDS TO NAVIGATION

In order to simulate the radio aids which are made use of by a pilot for fixing his position,

* Formerly with Redifon Ltd

for flying a course, and for landing the aircraft, it is necessary to have a device which will plot the aircraft's track and enable the various radio stations and beacons to be set in position.

Such a device is known as a track recorder, and for an aircraft in straight and level flight, it continuously solves the following equations:

Distance travelled in x direction
(west) $= \int (Vt \sin\psi)\, dt.$
Distance travelled in y direction
(north) $= \int (Vt \cos\psi)\, dt.$

where Vt is the airspeed, and ψ is the azimuth angle.

The result is recorded on a map of the flight area. By the addition of suitable voltages to the above equations, the effects of a wind can be included, which appropriately modify the recorded track.

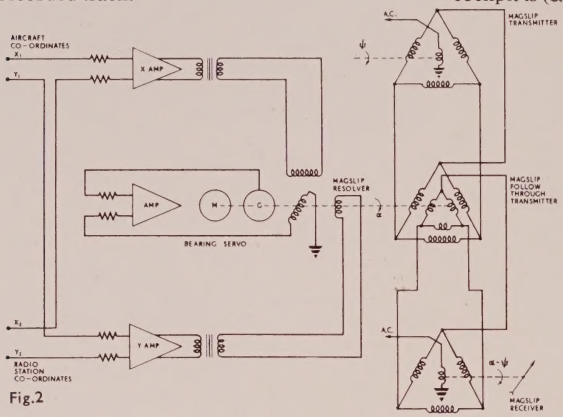


Fig.2

One of the oldest radio aids in use at the present time is the Automatic Direction Finder (A.D.F.) To use this equipment, the pilot tunes his A.D.F. receiver to the frequency of the radio station onto which he desires to 'home', and the servo operated loop aerial then rotates to a null position which is at right angles to the desired course. The position of the aerial operates an instrument in the cockpit, which indicates the bearing of the station relative to the aircraft heading. All that it is necessary for him to do now is to fly on a course that will reduce the reading of this instrument to zero. There are various audio signals connected with this system, with which this article is not concerned.

A schematic diagram of the simulated system is shown in figure 2.

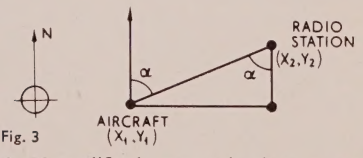


Fig. 3

The X amplifier is arranged to have an output proportional to X2 – X1, and the Y amplifier to have an output proportional to Y2 – Y1. I can be seen from figure 3 that the bearing of the radio station from the aircraft is given by:

$$\text{Tan } \alpha = \frac{X2 - X1}{Y2 - Y1}$$

These two signals are applied to the stator of a Magslip resolver, which is mounted on a standard servo unit, and driven by the motor through a reduction gear. With the output of the rotor fed to the amplifier, as shown, the servo will reduce this signal to zero, thereby rotating the resolver shaft through an angle α.

Referring to figure 4, it can be seen that the angle which is indicated to the pilot in the cockpit is $(\alpha - \psi)$.

In order to compute this angle, a Magslip transmitter is attached to the shaft of a servo in the flight computer which represents the azimuth angle ψ. It can be seen from figure 2 that this transmitter feeds the stator of a follow-through transmitter, whose rotor is rotated by the bearing servo to the angle α. Thus, by connecting the rotor winding of this follow-through transmitter to a Magslip receiver, the shaft of the receiver will rotate through an angle $(\alpha - \psi)$. This can be used to operate the instrument in the cockpit.

Another radio aid facility, which is used for landing aircraft when visibility is poor, is known as Ground Controlled Approach (G.C.A.). This is a radar system, operated from the far end of the runway, which tells the ground operator the horizontal and vertical

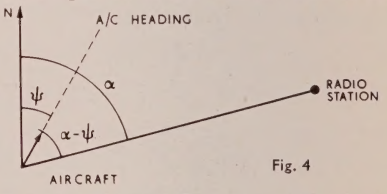


Fig. 4

approach angles and the range of the aircraft. With the help of this information, the ground operator 'talks down' the pilot over the V.H.F. ground-air communication system.

The schematic diagram of part of the simulated system is shown in figure 5.

As in the A.D.F. system, the bearing of the runway from the aircraft is computed in a Magslip resolver, which this time is hand operated. By orientating the resolver to the runway azimuth angle, the voltages obtained from the rotor windings, will represent the range of the aircraft along the line of the runway, and the perpendicular distance of the aircraft from this line.

The range signal is used to operate a servo

and a Magslip transmission system to indicate to the instructor (who represents the ground operator) the range of the aircraft.

The horizontal approach angle is obtained by computing the tangent of the angle from the two outputs of the resolver. For a small angle, this will be proportional to the angle. Another system makes use of the computed height and the range to indicate the vertical approach angle.

CONCLUSIONS

An attempt has been made to show how a number of Magslip elements find application in the field of flight-simulation. These are used not only as remote position control devices, but also in a number of computing applications. Their accuracy is consistent with that required in such a complex computing machine as a Flight Simulator.

ACKNOWLEDGEMENTS

The author wishes to thank the Directors of Redifon Limited, for permission to publish this article.

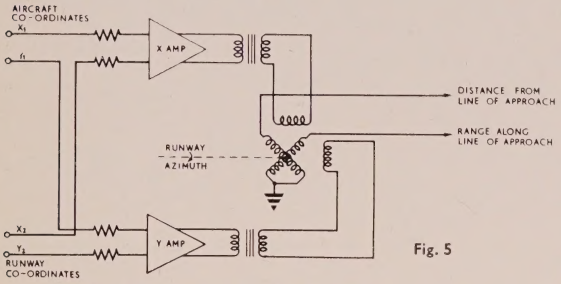


Fig. 5

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THE D-729 PHASEMETER AND SOME APPLICATIONS

by A. Cooper, B.Sc.(Hons.), A.M.I.E.E.*

(Continued from Vol. II No. 4)

The power factor of an inductor may be measured as shown in Fig. 7 in which R is made small compared with ωL. Then V_1 represents the voltage across the inductor and I the current through it. The voltage V_2 across R will be proportional to, and in phase with, the current I. With V_1 and V_2 fed to the phasemeter, their relative magnitudes and phase may be measured. Knowing R, the magnitude and power factor of the inductor can thus be found. If the current waveform is very distorted, it may be necessary to employ a selective amplifier as described previously.

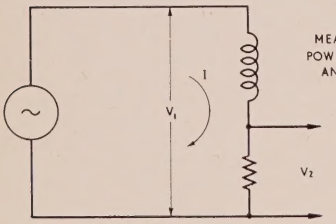

Fig. 7

PRACTICAL TESTS

1. Measurements of a Feedback Amplifier

It was required to construct an electronic amplifier suitable for energizing a 400 c/s feedback resolver. The specification demanded at least 40 dB negative feedback and an overall gain of two with feedback. Further, the size had to be extremely small. An amplifier was designed and built, its gain with the feedback circuit open being adjusted on test by using a D-729-A Phasemeter to measure the input and output voltages simultaneously. The resolver was tuned, adjustment of the feedback voltage phase at 400 c/s being also made on the phasemeter. When the feedback loop was closed the circuit self-oscillated at several kilocycles/second. A Nyquist plot was made of the region from a few c/s to 11 kc/s of the open-circuited loop giving curve 1 of Fig. 8. The amplitude was plotted in decibels hence the stability point is (0 dB, 0). It will be seen that the locus lay outside the point at about 9·5 kc/s. A correction network was calculated from this plot and its

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effect is shown in curve 2 which indicates a stable condition. Closing of the loop confirmed the stability. The outstanding features of the phasemeter in these tests were the two-channel facility and the 70 dB range of level difference, enabling rapid adjustment of gain and level to

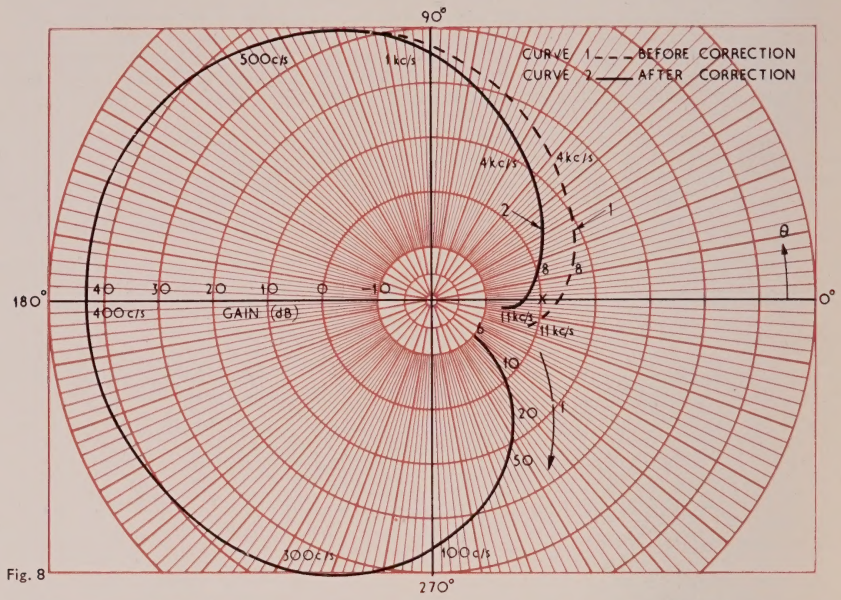

Fig. 8

be made, as well as phase.

The phase facility was found particularly useful when a transistor amplifier was designed to the same specification. The input impedances were much lower and coupling circuits required practical examination for phase-shift. This was found to be the most suitable method, since the input impedance of a transistor, unlike that of a thermionic valve, is very dependent upon the load impedance; it also includes a large capacitance which cannot be neglected even at 400 c/s.

2. Servo System Testing

Electro-mechanical servo systems such as those using Magslips or Synchros can be tested using the D-729-B Phasemeter. Since the output is usually mechanical, a suitable transducer is required. A typical servo is shown in Fig. 9, which was constructed from Magslips, with a Linvar (Linear Variometer) being used as a transducer.

The required oscillatory motion was imparted to the rotor of the control transmitter E-1-A/1 by means of a variable-speed d.c. motor via a gear box and crank. The three-phase stator of the transmitter was connected to the stator of the coincidence transmitter (control transformer) E-3-A/1 the rotor of which fed an error signal into a servo amplifier D-614-D. This error signal was amplified and drove a servo motor E-16-A/1 which in turn drove the coincidence transmitter until the error signal was substantially zero, i.e. until the rotors of the two transmitters were mutually at right angles.

As the circuit was self-oscillatory when excited by a momentary flick of the transmitter, an induction generator E-5-A/1 was coupled to the servo motor and applied damping to the system. The phase shift in the system was measured between one phase of the transmitter stator winding and the rotor of the coincidence transmitter, the Linvar converting the mechanical phase into an electrical one by being coupled to the output shaft and being excited by the common 50 c/s supply. Because the electrical signal consisted of amplitude-modulated 50 c/s, a demodulator was used in each channel to feed the appropriate channel of the phasemeter.

Diagrams of the closed loop transfer function were plotted without and with damping and are shown in Fig. 10. For convenience, the amplitude ratios are expressed in decibels.

Curve 1, without damping, exhibited a curious phenomenon. From 0·5 c/s to about 0·66 c/s, the phase shift was substantially zero, but at 0·67 c/s the phase changed quite suddenly to $-86°$ (or 274°), with a small increase in amplitude. Curve 2 with damping did not show this effect. A specially constructed tuned filter covering this low frequency range was used to determine whether some distortion which was present in the output was effecting the result, but this made little difference. An open loop characteristic was obtained by disconnecting the coincidence transmitter from the gear box and connecting another one as a mechanical load. The response is shown in Fig. 11.

A feature of the phasemeter illustrated by these measurements is that a reference signal can be derived from any convenient point in the system — it is not necessary to refer everything back to the mechanical input. Thus the

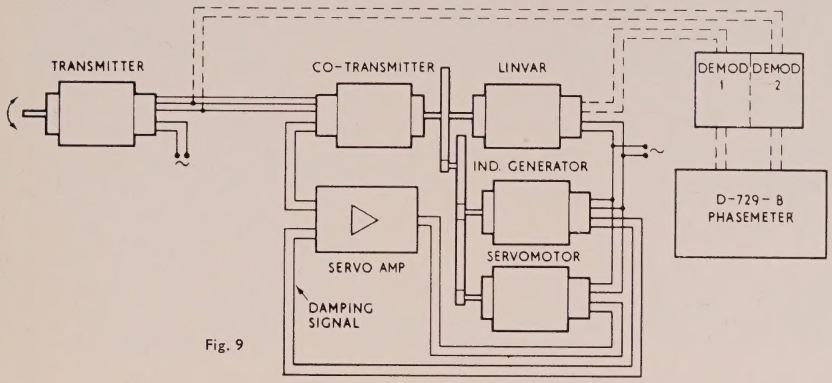

Fig. 9

performance of any element may be examined separately in situ.

CONCLUSION

In conclusion it may be stated that the versatility of the instrument has by no means been exhausted by the above applications. Two further examples can be mentioned briefly. Referring again to Fig. 2, it will be realised that if an output is taken from the METER INPUT socket and fed to the D-669 or D-788 Frequency Analyser, then greatly increased sensitivity can be obtained with the two amplifiers (one 'flat' and one tuned) in cascade. In a particular application it was found that a full-scale sensitivity of 50 microvolts was possible as compared with the normal 6 millivolts before circuit noise became troublesome. Of course, the analyser meter had to be used as the phase indicator but this was not a great complication since the voltage scale could be readily converted to a degree scale using the relationship quoted under 'Principles of Measurement'. Scale expansion to about 10 seconds of arc full-scale is theoretically possible in this set-up.

Finally, the balancing of small rotors has been performed much more accurately by

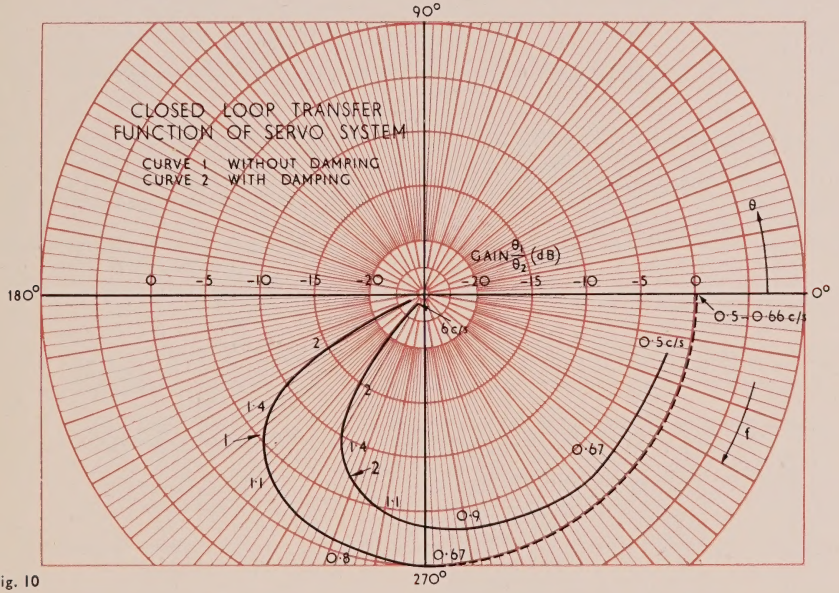

Fig. 10

using the phasemeter without or with a tuned amplifier. Measurement of vibration amplitude alone has not been found sufficient and phase difference measurements between the two ends of the rotor have yielded more useful design information.

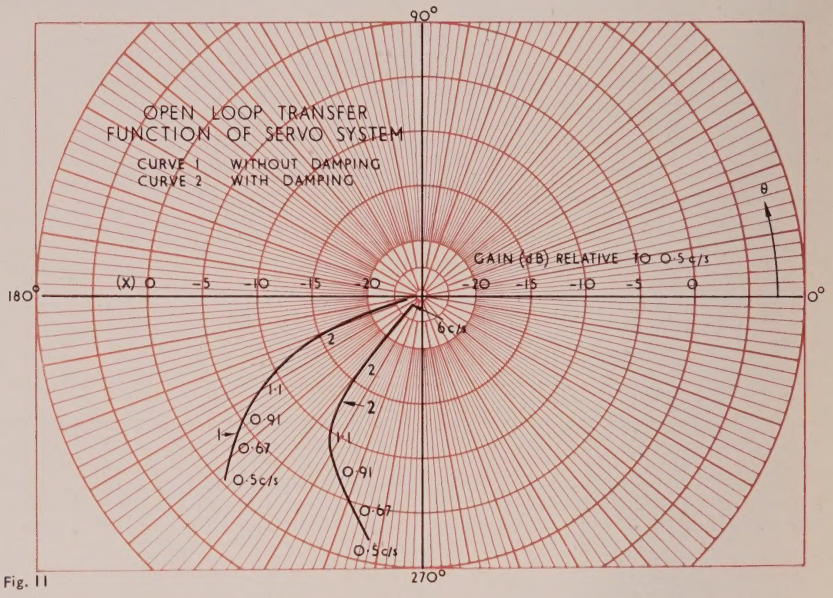

Fig. 11

ABRIDGED SPECIFICATIONS OF D-729-A AND B PHASEMETERS

	D-729-A	D-729-B
FREQUENCY RANGE	2 c/s–100 kc/s	0·5 c/s–10 kc/s
ACCURACY OF PHASE ANGLE MEASUREMENT	±1° from 5 c/s to 50 kc/s ±3° at 100 kc/s and 2 c/s	±1° above 2 c/s ±3° at 0·5c/s
*RANGE OF INPUT VOLTAGE FOR PHASE MEASUREMENT	5mV to 20V above 10 c/s 30mV to 20V at 2 c/s	5mV to 20V above 1 c/s 10mV to 20V at 0·5 c/s
PERMISSIBLE DISTORTION OF INPUT VOLTAGE	5%	5%
ACCURACY OF VOLTAGE MEASUREMENT	±5% above 10 c/s	±5% above 2 c/s
MAXIMUM DIFFERENCE OF INPUT LEVELS	70 dB above 10 c/s 55 dB at 2 c/s	70 dB above 2 c/s 60 dB at 0·5 c/s
ACCURACY OF LEVEL DIFFERENCE	±2% above 10 c/s	±2% above 2 c/s ±5% at 0·5 c/s
IMPEDANCE AT INPUT SOCKETS	30 megohms in parallel with 15 pF	30 megohms in parallel with 15 pF
POWER SUPPLY	190–250V, 50 c/s (– B) 95–125V, 60 c/s (– B/100)	

*With D-850 Attenuator Probe Unit 200 volts. Input impedance 1 megohm in parallel with 10 pF.

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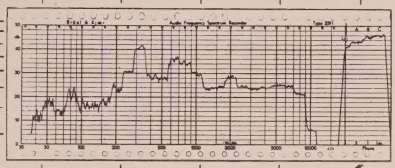
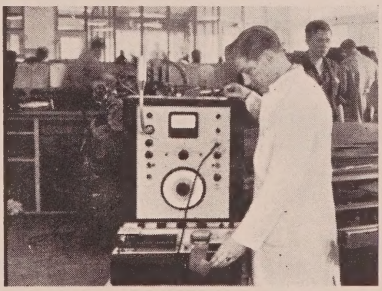
Technical Review

To advance interest in the measurements of Sound, Vibration and Strain



Noise Measurements and Analyses



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No. 4 • 1955

Fig. 1 indicates the significance of the above definitions with regard to a periodic signal of period T.

The rectifying circuit of an instrument can be designed to give a D. C. output voltage proportional to anyone of the three different definitions of the A. C. input voltage given above. Furthermore the rectifier might be designed as a half wave rectifier, i. e. only the positive (or negative) half period of the A. C. voltage is present at its output, or it might be a full wave rectifier. This is illustrated in fig. 2.

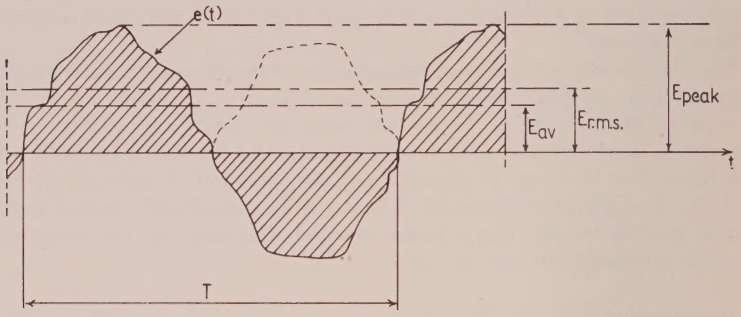

Fig. 1. Example of a periodic signal with indication of the peak, r. m. s. and average value of the voltage.

It is thus obvious that the deflection on the instrument meter will depend upon which type of rectifying circuit is employed.

Normally a rectifier giving a D. C. output voltage proportional to the average value of the A. C. input voltage measured is incorporated in audio frequency measuring instruments.

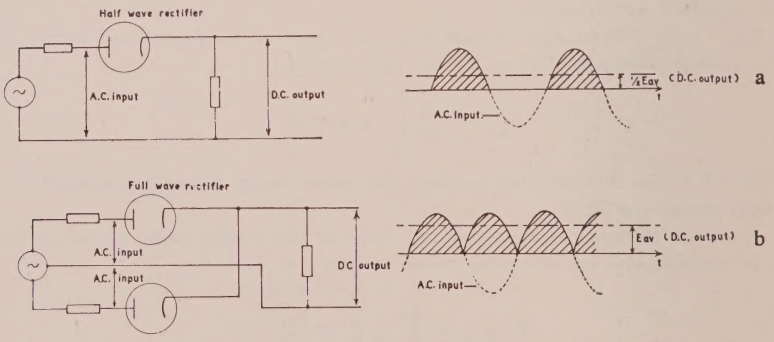

Fig. 2. Basic diagram of a rectifying circuit the output voltage of which is proportional to the average value of the input signal.
a) Half wave rectifier.
b) Full wave rectifier.

When calibrated with a sinusoidal signal the meter scale may be graduated in average, peak or r. m. s. values without any loss of generality, as in this case only a mathematical transformation of the different expressions for the A. C. voltage is necessary. However, when the input A. C. signal is not a sine wave, instruments calibrated with a sine wave voltage will give different readings, depending upon the type of rectifier circuit employed.

Both Microphone Amplifier Type 2602, Audio Frequency Spectrometer Type 2109 and the A. F. voltmeters produced by B & K are supplied with rectifiers, the output voltage of which is proportional to the average value of the A. C. input voltage. The instrument meters are normally calibrated in r. m. s. values of a sinusoidal input signal.

However, the Level Recorder Type 2304 employs a peak value rectifying circuit.

Due to the complicated nature of a noise signal the measured result obtained from the Level Recorder will differ from that obtained by reading off the scale of the instrument meter, both instruments having been originally calibrated by means of a sinusoidal reference signal.

Experimental results have shown that when a random noise signal is used for calibration the difference in measured results obtained from the two types of indications are largely reduced, and some of these experiments will now be discussed.

A number of tests have been carried out and data returned to our laboratory examined in order to determine the degree of correlation that could be expected over a wide range of conditions.

The occasions for comparing these data have almost invariably been a comparison of band type analyses, either octave band or third octave band, read either on a meter or graphically recorded, and therefore the data will be presented in each instance as read both linearly and through a series of filters. These tests were all made on the Audio Frequency Spectrum Recorder Type 2311. The instrument comprises a $^1/_3$ octave band filter system and associated amplifiers with the standard ASA approved average reading meter in the output. The output of this third octave filter system can likewise be applied to the Level Recorder which is combined with it. It is, therefore, possible to compare the output from the third octave filter system both on the average reading meter and on the Level Recorder. The detection circuit in the average reading meter utilizes a full wave average rectifier and in the case of the Level Recorder the detection circuit is a half wave diode rectifier network.

The objective was to make the following comparisons:

1. To compare the meter reading and the graphic level recording of two different types of signals; random noise and jet engine noise when both instruments had been calibrated with the same signal either random noise or sine wave.
2. To compare the readings on the two different instruments when the calibration has been made on the Level Recorder by taking the overall

reading of the sound level meter as the overall reading for the Level Recorder, arbitrarily selecting a deflection to represent this value.

Many of the natural noises have a Gaussian distribution of amplitude; examples of these are white random noise, noise from jet engines, and other similar broad band noises. For this type of signal, even when both instruments have been calibrated with a sine wave signal, the maximum deviation encountered between the meter reading and the Level Recorder paper indication for any filter setting as well as on "linear" was 3 to 4 db. In Table I, shown below, is an illustration of the readings obtained when white random noise was used to calibrate both instruments and then a 1000 cycle sine wave and 60 cycle sine wave were applied with the same average level. The resulting readings indicate the normal deviation that can be expected for the two different types of signals. The difference in the level obtained for 1000 cycle sine wave calibration and 60 cycle sine wave calibration is attributable to the amplifier gain of the Level Recorder dropping slightly at the 60 cycle point with respect to 1000 cycle.

Table I.

Calibration Signal Comparison on Average Reading Sound Level Meter Type 2109 and Peak Responding Level Recorder Type 2304.

Calibration Signal:	S.L.M. Reading:	Level Recorder Indication:
*) White Noise	100 db	100 db
1000 cycles	100 db	98 db
60 cycles	100 db	97 db

*) Vacuum Tube Noise Amplified.

This shows the type of conditions that might be encountered and illustrates the difference in sound level readings that could be expected. In order to obtain the highest degree of correlation, the recommended procedure is to use the signal to be analysed and take an overall reading from the Sound Level Meter, which will be an average reading, and use this reading to set a corresponding calibration on the Level Recorder. The calibrations now hold for this particular type of signal whatever it may be.

The factors which could introduce inaccuracy when the total noise reading on the Sound Level Meter is used to calibrate the over-all reading of the Level Recorder will now be considered. In those instances where random noise constitutes the background noise of the signal and there are one or more pronounced single resonant frequencies of a more sinusoidal character which are 10 to 30 db higher than the overall white noise background, a difference of up to 2 db can be encountered in the two readings of the level for any single $^1/_3$ octave band as read on the instrument meter and on the Level Recorder. (For random noise with a frequency drop-off of the order of 6 to 12 db per octave the Level Recorder will read approx. 2 db higher than the meter reading for the filter bands in the upper frequency

range). The filter bands containing the predominant sinusoidal waves will show a reading of approx. 1 db lower on the Level Recorder. These effects are produced primarily by the digression of the wave form of the signals, within any individual pass band, from the overall characteristics of the total signal which is used for the calibration.

In Table II, tape recorded jet engine noise was fed into the Audio Frequency Spectrum Recorder Type 2311 and the sequential filter analysis performed with data being tabulated directly from the average reading meter in the analyzer section and simultaneously recording the level on the peak responding Level Recorder. The instrument meter section and the Level Recorder were both calibrated such that they gave the same overall reading for the jet engine noise. It will be noted that a rather close correlation throughout the entire spectrum has been maintained. Some difficulty was encountered in reading the lower filters because of considerable fluctuation in the readings and a degree of inaccuracy may be attributed to this. A check was made of the difference when the Level Recorder was calibrated with a sine wave signal. The readings differed by as much as 2 to 3 db as would be expected from the previous test.

Table II.

EXAMPLES OF CORRELATION OBTAINABLE

When the Signal for Analysis is Used to Give the Same Overall Reading on Both Average and Peak Responding Instruments.

Filter Frequency	Sound Level Meter Reading	Lev. Rec. Indication	Filter Frequency	Sound Level Meter Reading	Lev. Rec. Indication
linear	110	110	1.600	98	98
16.000	91	91	1.250	98.5	98.5
12.500	96	96	1.000	98	98
10.000	94	94	800	98	97.5
8.000	92.5	92.5	640	98.5	98
6.400	92.5	93	500	97	96
5.000	93.5	94	400	96.5	96
4.000	94.5	94.5	320	97	96
3.200	95.5	95.5	250	96.5	95
2.500	96.5	97	200	95	93
2.000	97.5	98	160	89	88
			125	86	85
			100	86	85
			80	85	84
	Readings Difficult Due to Level Fluctuation		64	83	81
			50	89	85
			40	82	82

Noise Type — Jet Engine Exhaust. N A C A Data.

The greatest degree of deviation between the two types of readings will be encountered in a random type noise with a steep decay slope in the upper spectrum. Such a signal has been utilized in Table III in the form of random noise produced by the first amplifier stage of an instrument.

Fig. 3 shows the total spectrum of the noise as recorded on the Automatic Spectrum Recorder Type 2311 after calibration of the recording paper with the aid of a sine wave reference signal of 60 c/s. The recording was taken with gear wheel D inserted and a paper speed 0.3 mm/sec, allowing a time of 16 sec. for each separate filter. This rather long measuring time is advisable due to the fluctuating nature of the noise with time. A good estimation of the average noise level is thus obtained.

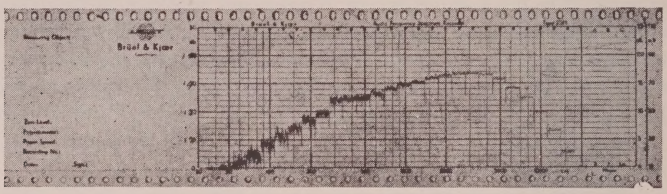

Fig. 3. Spectrogram of the noise produced by the first amplifier stage of an instrument.

Table III.

Comparison of 1/3 octave meter readings and level recorder chart paper indications after calibration with 60 c/s reference tone, as well as with over all sound level.

Filter Frequency in c/s	S.L.M. Reading	Level Recorder Reading 60 c/s Calibration	Level Recorder Reading; Overall Level Calibration
100	110	118	113½
160	118	124	119½
250	122	129	124½
400	131	135	130½
640	132	136½	132
1.000	135	139	134½
1.600	137	142	137½
2.500	138	143½	139
4.000	138	143	138½
6.400	133	138½	134
10.000	123	130	125½
16.000	108	115½	111
lin.	**147**	151½	**147**

It is noted that in the "flat" part of the spectrum between 900 and 6400 c/s the difference in S. L. M. reading and Level Recorder indication is rather small

when the overall sound level is used for calibration. Both for the lower and higher frequencies deviations between meter and paper reading is greater. At the lower frequencies the accuracy of the fluctuating meter reading plays a role, but at the higher frequencies the spectrum slope within one filter range is apparently the only reason for the discrepancy. The peak value of the greatest component within one $^1/_3$ octave filter band contributes more to the peak responding Level Recorder indication than to the average value of the total noise signal as indicated by the Spectrometer meter.

From the described experiments, and other measured results, it is thus found that a calibration of the instruments by means of the overall noise level might be practical in many cases where noise voltages are measured or analyzed. In case the meter reading is too inaccurate for calibration, due to the fluctuations in the noise, a random noise generator can be successfully employed.

Cleveland, Ohio. *Willem Brand.*

ACKNOWLEDGMENT

Thanks are due to Mr. James W. Day of Brush Electronics Company for initiating and contributing to these investigations.

NOISE MEASUREMENTS AND ESTIMATION OF TOTAL LOUDNESS IN SONES BY SPECTRUM ANALYSES

by

Willem Brand M. Sc.

and

Jens T. Broch M. Sc.

The evaluation of noise from measurements of sound pressure level taken in different frequency bands is of considerable practical interest for all noise reduction work.

Different types of analysis are employed for this evaluation, dividing the noise spectrum into several contiguous frequency bands. A common type of analysis is performed by dividing the spectrum into a number of octave bands. However, bandwidths of 1/2 octave or 1/3 octave may also be used, the conversion factors for the evaluation of the loudness in sones are then different from those employed for full octave band analysis.

In most cases an evaluation of the noise level based on 1/3 octave bandwidth will give far more valuable information with regard to the character of the noise than will be achieved with a 1/2 octave or octave band analysis.

This article discusses the use of 1/3 octave bandwidths for noise measurements and indicates how the Audio Frequency Spectrometer Type 2109 (or the Audio Frequency Spectrum Recorder Type 2311) can be applied.
The treatment is based on investigations recently made by professor Stevens of the Psycho-Acoustic Laboratory at Harvard University, and a comparison is made between octave band analysis and 1/3 octave band analysis.

Loudness is a subjective quantity and cannot be measured exactly with any instrument. It is defined as that aspect of auditory sensation in terms of which sound may be gradated on a scale running from "soft" to "loud". It is chiefly a function of the sound pressure level, but it is also dependent on the frequencies and the composition of the sound. The loudness of sound is related to the total wave energy produced by the sound in the ear, whence it is sent to the brain.

To establish a scale of loudness as a function of the sound pressure level in decibels subjective measurements are made with a pure tone. Normally the frequency of this tone is 1000 c/s and a reference level is chosen at 40 db re 2×10^{-4} μbar $=$ 1 sone. A loudness of 10 sones is then twice as loud as 5 sones and 10 times as loud as 1 sone. Furthermore 1 sone $=$ 1000 millisones. Fig. 1 shows the relationship between loudness in millisones and loudness level in phons. At 1000 c/s the loudness level in phons corresponds to the sound pressure level in db re 2×10^{-4} μbar.

However, the loudness of a sound of a given sound pressure level at one frequency may be quite different from the loudness of a sound of the same sound pressure level at a different frequency. By subjective measurements listeners can adjust the loudness of one tone to match the loudness of another tone. The results obtained from such experiments can be plotted in a fre-

quency-decibel chart and are referred to as equal loudness contours. Equal loudness contours for pure tones are shown in fig. 2.

It is also possible to determine equal loudness contours for other sounds than pure tones e.g. a random type noise. The normal procedure is then, by means of filters, to cut out certain frequency bands of the noise under consideration and compare the loudness of these bands with that of a 1000 c/s pure tone. The shape of the equal loudness contours will then depend upon the bandwidth of the filters employed for the measurements.

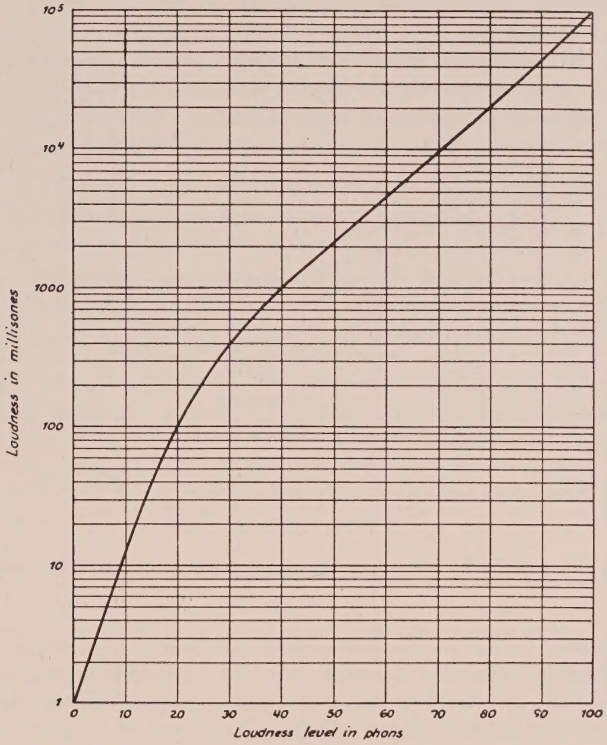

Fig. 1. Loudness in sones as a function of the loudness level in phons.

Because of the introduction of phons which indicate the dependency of loudness upon frequency (see fig. 2) the curve of fig. 1 applies to sound of any frequency, or combination of frequencies. If the loudness level of a sound is 40 phons, it will have a loudness of 1000 millisones, if the loudness level is 70 phons, it will have a loudness of 10,000 millisones. A reduction of the loudness level from 70 to 40 phons then corresponds to a tenfold change in loudness.

In equivalent tone methods of noise loudness calculation the following procedure has been employed up to now:

1. The noise is divided into several contiguous frequency bands.
2. The sound pressure level of each band is measured.
3. The measured sound pressure level in each band is treated as if it was concentrated at a frequency in the middle of the band, and a value of loudness in sones is then calculated for each mid-frequency.
4. The values from 3 are added arithmetically, whereby the total loudness is determined.

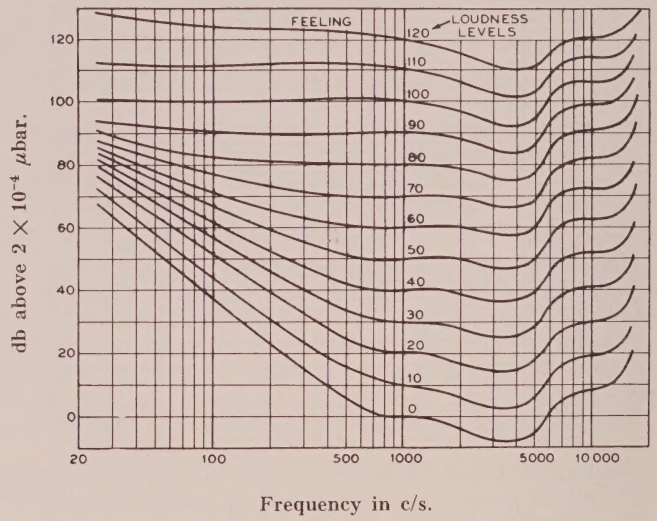

Fig. 2. Sensitivity curves of the human ear (Fletcher - Munson).

For practical noise measurements with the Spectrometer Type 2109 or Audio Frequency Spectrum Recorder Type 2311 the division into frequency bands according to point 1. is fixed. The total spectrum is divided in 27 contiguous 1/3 octave bands ranging from 35.5 — 45 — 56 — 71 — 90 — 112 — 140 — 180 — 224 — 280 — 355 .... 14000 — 18000 c/s.

Point 2 concerns the actual measurement of the noise level within each 1/3 octave band. When using Spectrometer Type 2109 the value read off the meter indicates the r. m. s. value of a pure sinusoidal voltage. However, the meter itself is of the average type and for random noise the reading will be approx. 1 db lower than the actual r. m. s. value of this type of signal. (see Beranek: Acoustic Measurements, p. 453). The rectifier and meter system in Type 2109 correspond exactly to the new proposed standards which will be approved officially by A. S. A. very shortly.

In case the Level Recorder of the Audio Frequency Spectrum Recorder Type 2311 is used as indicating instrument care should be taken regarding the calibration of the instrument because the detector circuit employed in the Level Recorder gives an output voltage corresponding to the peak value of the input signal.

A useful method of calibration is described in the preceding article, and shows that it might be carried out by means of an overall reading of the total noise level, the Spectrometer filter switch being in position "Linear".

Point 3 in the procedure to be followed when loudness calculations are made gives rise to some difficulties. In principle the problem does not look complicated at all. However, different methods are unfortunately employed for the estimation of the sone value corresponding to the sound pressure level measured for each separate frequency band. Large discrepancies are thus found in practice when different measurements are compared, even if the measurements are taken with one and the same noise source.

The largest discrepancy can be expected where the loudness of the noise, based on an octave band analysis, is compared to the loudness calculated from measurements with frequency bands of 1/3 octave.

As previously mentioned, the conversion chart for evaluation of loudness in sones is based on a family of curves of equal loudness expressed in phons.

When phon curves are established for all kinds of noises and bandwidths the determination of loudness in sones follows immediately.

However, for 1/3 octave bands of white random noise there still exists no equal loudness contours based on sufficient subjective measurements.

IBM has therefore, for routine measurements, established conversion tables based on fig. 1 and fig. 2. Table I illustrates the use of these tables, showing how the measured sound pressure levels are converted into their respective sone values.

Table I.

1000 c/s 1/3 octave band	200 c/s 1/3 octave band
20 db = 0.10 sone	40 db = 20 phon = 0.10 sone
30 db = 0.34 sone	46 db = 30 phon = 0.34 sone
40 db = 1.00 sone	53 db = 40 phon = 1.00 sone
50 db = 2.15 sone	59 db = 50 phon = 2.15 sone
60 db = 4.64 sone	66 db = 60 phon = 4.65 sone
70 db = 10.00 sone	73 db = 70 phon = 10.00 sone
80 db = 21.60 sone	81 db = 80 phon = 21.60 sone
90 db = 47.00 sone	90 db = 90 phon = 47.00 sone
100 db = 100.00 sone	100 db = 100 phon = 100.00 sone

A similar type of conversion table is given in the Handbook of Noise Measurements published by General Radio Co.[2]) The data given in the hand-

book are valid for octave band analysis, and are no more based on fig. 2 but on the equal loudness contours shown in fig. 3.

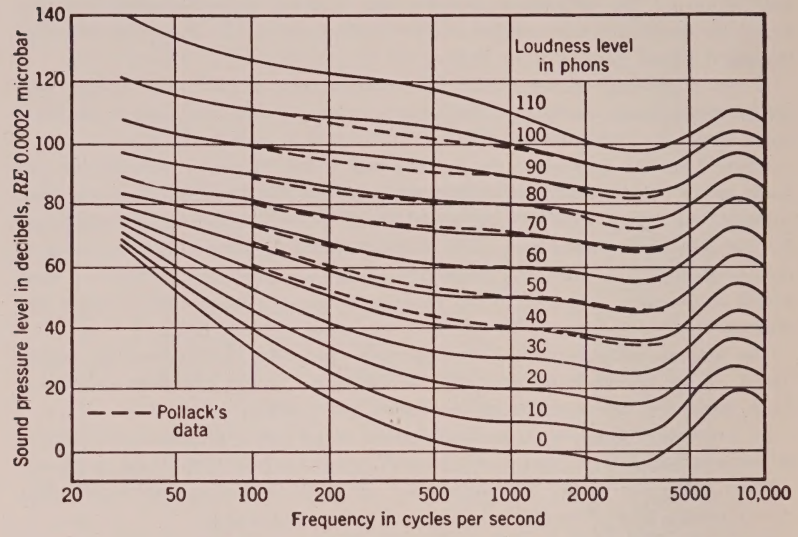

Fig. 3. Equal loudness contours for pure tones by Curcher-King and for a 250-mel band of noise by Polack.

It should be noted that the frequency bands used to obtain these equal loudness contours were not actually 1 octave wide, but had subjectively felt equal widths for the average listener, expressed in mels. As equal bands of mels do not correspond to octave bands, the application of these data is open to discussion.[3])

Table II.

600—1200 c/s octave band	150—300 c/s octave band (fig. 3)	212 c/s (according to fig. 2)
20 db 0.10 sones	38 db 0.26 sones	38 db = 20 phon = 0.10 sones
30 db 0.36 sones	44 db 0.58 sones	44 db = 30 phon = 0.36 sones
40 db 1.00 sones	51 db 1.20 sones	51 db = 40 phon = 1.00 sones
50 db 2.15 sones	59 db 2.40 sones	59 db = 50 phon = 2.15 sones
60 db 4.60 sones	65 db 4.10 sones	65 db = 60 phon = 4.60 sones
70 db 10.00 sones	72 db 7.80 sones	72 db = 70 phon = 16.00 sones
80 db 22.00 sones	80 db 14.50 sones	80 db = 80 phon = 22.00 sones
90 db 47.00 sones	90 db 30.00 sones	90 db = 90 phon = 47.00 sones
100 db 100.00 sones	100 db 58.00 sones	100 db = 100 phon = 100.00 sones

From table II is seen that for the 600—1200 c/s octave band the sone values (or transfer values as they are called in the Handbook) correspond di-

rectly with fig. 1. For the 150—300 c/s band, however, (mean frequency 212 c/s) the difference in sone values when derived from fig. 2 or fig. 3 are quite evident.

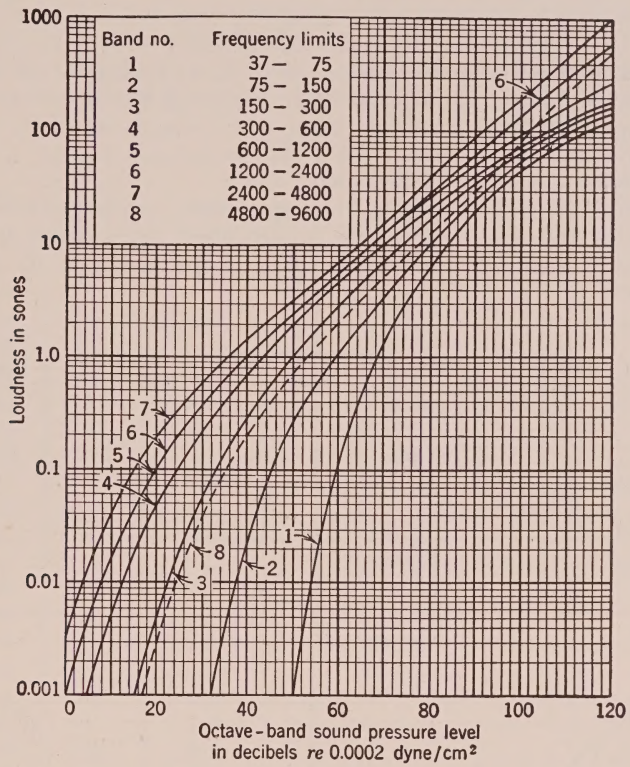

Fig. 4. Chart for converting from octave-band levels in decibels to loudness in sones. The chart is strictly accurate only for continuous spectrum noises. The total loudness of a wide-band continuous spectrum noise is determined by adding together the loudness for each band. (After Beranek and Peterson).

Fig. 4 shows a graph from which the sone value can be directly found when the sound pressure level is measured in db re 2×10^{-4} μbar, without employing fig. 3. The graph is based on octave band analysis, and a somewhat similar chart has been published in the manual for the Spectrometer Type 2109, which might be used when a bandwidth of $^1/_3$ octave is employed.

At the meeting of the Acoustical Society of America in December 1955 Professor Stevens of the Psycho-Acoustic Laboratory at Harvard University proposed a new method of calculating the total loudness in sones. According to results obtained from subjective tests the assumption that loudness bands

should be added to yield the total loudness value is, in his opinion, wrong. The tests show that the loudness of each separate band can be combined according to the formula

$$S_t = S_m + F\,(\Sigma s - S_m)$$

S_t is the loudness in sones of the total noise, S_m the loudness of the loudest band, Σs the sum of the loudness of all bands together, and F a factor which varies with the conditions under which measurements are taken. For octave band measurements F has a value around 0.27, and for $^1/_3$ octave measurements F should lie between 0.11—0.16.

Employing the formula given by Professor Stevens combined with the data prepared by IBM, discrepancies between calculations based on octave band analysis and those based on the use of $^1/_3$ octave bands can be almost eliminated.

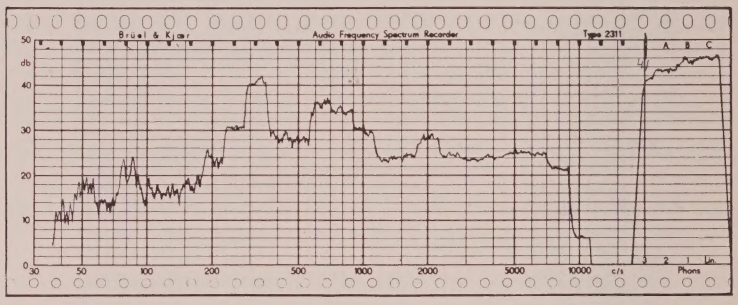

Fig. 5. Spectrogram of a small lathe.

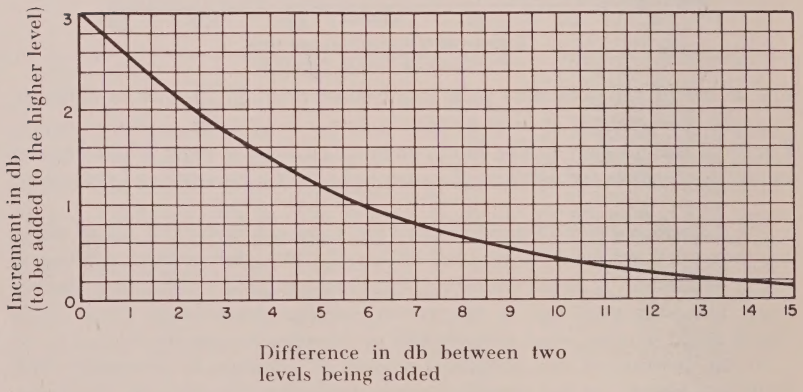
Increment in db
(to be added to the higher level)
3
2
1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Difference in db between two
levels being added

Fig. 6. Chart for combining noise levels (G. R. Handbook of noise measurement).

Fig. 5 shows the spectrogram of the noise from a small lathe, and in table III the calculations of the total loudness in sones are given. Using the IBM-tables for conversion of sound pressure levels in db into loudness values in sones, and applying the above formula an exactly equal total loudness is found.

The factor F = 0.15 is chosen to show how the results of these two different types of analysis can be brought into complete agreement.

Even if a factor F = 0.13 is chosen (average value of the interval 0.11—0.16 given by Stevens), the result is still quite satisfactory.

Table III.

Midfrequency of 1/3 octave filter c/s	Sound pressure level in db (measured with 2311)	Loudness value according to IBM-tables (sones)	Equivalent octave band	Equivalent S.P.L. in db for octave band	Loudness value according to IBM tables (sones)
40	32	0	35.5— 71	40	0
50	38	0			
63	33	0			
80	41	0			
100	37	0	71— 140	43	0
125	36	0			
160	38	0			
200	44	0.23	140— 280	52	0.86
250	51	1.11			
315	61	3.92 (1.55)			
400	48	1.47	280— 560	61	4.80
500	48	1.67			
630	56	3.42 (1.59)			
800	54	2.93	560—1120	59	4.30
1000	50	2.15			
1250	44	1.36			
1600	44	1.36	1120—2240	51	2.33
2000	49	2.01			
2500	45	1.63			
3150	44	1.63	2240—4480	49	2.51
4000	44	1.75			
5000	45	1.47			
6400	45	0.83	4480—8960	49	1.15
8000	41	0.98			
10000	26	0			
		Σ = 29.92 sones			Σ = 15.95 sones

Total loudness:
(Bandwidths of 1/3 octave)
$S_t = S_m + 0.15\ (\Sigma s - S_m)$
$S = 3.9 + 0.15 \times 26 =$
7,8 sones

Total loudness:
(Bandwidths of 1 octave)
$S_t = S_m + 0.27\ (\Sigma s - S_m)$
$4.8 + 0.278 \times 11.15 =$
7.8 sones

The sound pressure levels given in table III for octave band analysis are found from fig. 6. This figure shows how different noise levels can be combined to yield the total noise level present.

As previously mentioned the IBM conversion tables are based on fig. 1 and 2. It may well be assumed that there will be a considerable difference in the two sets of contours to be used respectively with 1/3 octave and one octave band analysis. Recent tests performed with octave bands of white random noise appear, according to Stevens, to differ considerably from both the pure tone contours (fig. 2) and the contours given in fig. 3.

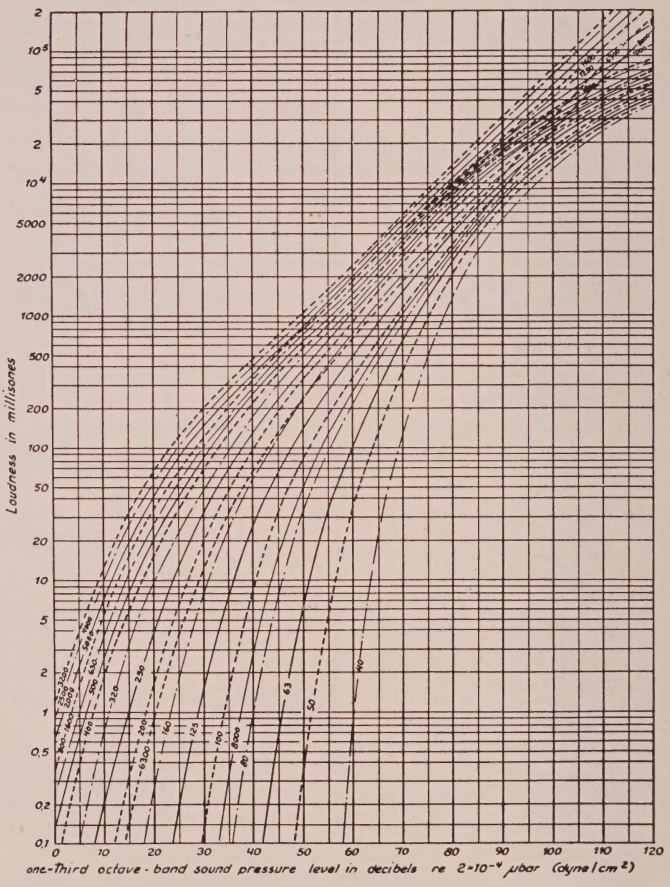

Fig. 7. Loudness in millisones for 1/3-octave filters as a function of sound pressure level in db re 2×10^{-4} μbar.

For the sake of comparison the important methods known until now concerning the conversion of spectrum measurements into a total loudness value, are listed below.

The different methods are then applied to the noise spectrum of the small lathe, as shown in fig. 5 and the discrepancies are clearly noticed.

1. The sound pressure levels in db re 2×10^{-4} μbar for different octave bands are converted into their respective sone values with the aid of fig. 4 and added arithmetically (Octave band analysis).
2. The sound pressure levels in db for different 1/3 octave bands are converted into their respective sone values with the aid of fig. 7. The curves shown in fig. 7 are the same as the curves originally published in the manual for Type 2109. (1/3 Octave band analysis).
3. The sound pressure levels in db for different octave bands are converted into their respective sone values with the aid of the IBM tables, and Stevens' formula for octave band analysis applied to obtain the total loudness.
4. The sound pressure levels in db as measured with the Spectrometer Type 2109 are converted into their respective sone values with the aid of the IBM tables, and Stevens' formula for 1/3 octave analysis applied to obtain the total loudness.

The evaluation according to method 1) is shown in table IV. The total loudness in sones is then 16,0 sones which corresponds to a weighted total sound pressure level of approx. 77 phons (see also fig. 1).

Table IV.

Octave band	S. P. L. in db re $2\times10^{-4}\mu$bar	Loudness in sones
35.5— 71 c/s	40	0
71 — 140 c/s	43	0.06
140 — 280 c/s	52	1.2
280 — 560 c/s	61	4.4
560 —1120 c/s	59	5
1120 —2240 c/s	51	2.7
2240 —4480 c/s	49	2
4480 —8960 c/s	49	0.6
	Total loudness:	16.0

By employing method 2), a total loudness in sones of 10.1 sones is found, which corresponds to a weighted total sound pressure level of approx. 71 phons. See also table V.

The evaluation of the total loudness according to method 3 is given previously (Table III, p. 15), resulting in a total loudness of 7,8 sones, which corresponds to a weighted total sound pressure level of 67 phons.

Table V.

1/3 octave Band (Center Frequency, c/s)	S. P. L. in db re 2×10^{-4} μbar	Loudness in sones
40	32	0
50	38	0
63	33	0
80	41	0.001
100	37	0.003
125	36	0.009
160	38	0.042
200	44	0.18
250	51	0.4
315	61	1.2
400	48	0.5
500	48	0.55
630	56	1.55
800	54	1.1
1000	50	0.8
1250	44	0.47
1600	44	0.47
2000	49	0.75
2500	45	0.62
3150	44	0.61
4000	44	0.56
5000	45	0.55
6400	45	0.13
8000	41	0.004
10000	26	0
	Total loudness:	10.099

However, employing the IBM tables for octave band analysis, the conversion from decibels to sones should be performed at the following frequencies:

Band Limits:	*Frequency:*
37,5— 75 c/s	50 c/s
75 — 150 c/s	100 c/s
150 — 300 c/s	200 c/s
300 — 600 c/s	400 c/s
600 —1200 c/s	800 c/s
1200 —2400 c/s	1600 c/s
2400 —4800 c/s	3150 c/s
4800 —9600 c/s	6300 c/s

Exactly the same result is obtained when employing method 4 for the evaluation and choosing the value 0.15 for F.

The reading on the meter (or rather on the recording) for the weighted sound pressure level also gives 67 phons.

To obtain an idea of the inaccuracy of the loudness evaluation due to the choice of a "wrong" F-factor in Stevens' formula for 1/3 octave analysis, the lower limit for this factor (F = 0.11) gives for the noise Spectrum of fig. 5:

Total loudness:	6.76 sones
Total weighted S. P. L.:	approx. 63 phon

Until a reliable set of equal loudness contours for 1/3 octave and one octave white random noise measurements is published, it is difficult to advise any specific method of evaluation. It seems however, that the method proposed by Stevens, when properly used, will give quite satisfactory results.

The advantage of 1/3 octave type of sound-spectra analyses, compared with one octave measurements, lays not so much in the establishment of an overall subjective loudness value of any particular noise, but in the details it gives to the noise abatement engineer, trying to ascertain in which direction his endeavours to silence the noise source under consideration should be directed. The spectrum shown in fig. 5 indicates clearly that certain parts of this machinery radiate a considerable amount of sound energy in the narrow frequency range 280—350 c/s. The second harmonic, possibly generated through a 1:2 gear connection, is also prominent.

From table III it follows that, reducing the noise 10 db in these two bands only, e. g. by appropriate sound insulation of the gear box, the sone values are more than halved (figures within brackets). The total loudness will then be $S_t = 2.93 + 0.15 \times 25.72 = 6.8$ sones.

The octave band analysis shows a constant level of approx. 60 db over the total range of two whole octaves from 280—1120 c/s, and does not give sufficient information as to where a succesful noise reduction technique should be applied.

It is interesting to see how the new addition rule, given by Professor Stevens, even more than before, emphasizes the importance of the loudest part of the considered noise spectrum.

An analysis based on 1/3 octave bands will therefore be of more value to the abatement engineer than will an analysis based on 1 octave bands.

The evaluation of the measurements as described in this article has been based on the assumption of ideal filters, i. e. filters having zero insertion loss in the passband and infinite attenuation outside this band.

No practical filters have such characteristics, and a method of correcting the results taking the finite slope of the actual filter curve into account is given in General Electrics Report No. R53 GL 119—1.[4]) For the Audio Frequency Spectrometer Type 2109 this corection factor will be of the order of 0.2 to 0.6 db for white random noise and should be subtracted from the measured noise level before using the IBM conversion tables.

References:

1) Lecture given by Professor Stevens at the december meeting of the Acoustical Society of America in Providence 1955.

2) G. R. Handbook of Noise Measurements, p. 73. General Radio Company, 1953.

3) J. A. S. A. Vol. 23, 1951, p. 261—269.

4) General Electric Report No. R53 GL 119—1, p. 32—50.

Acknowledgment.

Thanks are due to Mr. Joseph Abruzzo of International Business Machines for his kind permission to use the Loudness Conversion Tables of Appendix I.

APPENDIX I.

LOUDNESS CONVERSION TABLES

(I. B. M.)

SOUND PRESSURE LEVEL IN DECIBELS TO LOUDNESS IN SONES

DB	40~	DB	50~	DB	63~	DB	80~	DB	100~	DB	125~	DB	160~
40		40		40		40		40		40		40	
41		41		41		41		41		41		41	
42		42		42		42		42		42		42	
43		43		43		43		43		43		43	0.10
44		44		44		44		44		44		44	0.12
45		45		45		45		45		45		45	0.15
46		46		46		46		46		46		46	0.18
47		47		47		47		47		47	0.10	47	0.23
48		48		48		48		48		48	0.12	48	0.28
49		49		49		49		49		49	0.15	49	0.34
50		50		50		50		50		50	0.18	50	0.40
51		51		51		51		51	0.10	51	0.23	51	0.47
52		52		52		52		52	0.12	52	0.28	52	0.54
53		53		53		53		53	0.15	53	0.34	53	0.63
54		54		54		54		54	0.18	54	0.41	54	0.73
55		55		55		55	0.10	55	0.23	55	0.49	55	0.86
56		56		56		56	0.13	56	0.28	56	0.58	56	1.00
57		57		57		57	0.16	57	0.34	57	0.70	57	1.17
58		58		58		58	0.21	58	0.42	58	0.84	58	1.36
59		59		59		59	0.27	59	0.52	59	1.00	59	1.59
60		60		60	0.10	60	0.34	60	0.65	60	1.17	60	1.85
61		61		61	0.14	61	0.42	61	0.81	61	1.36	61	2.15
62		62		62	0.18	62	0.52	62	1.00	62	1.59	62	2.40
63		63		63	0.25	63	0.65	63	1.17	63	1.85	63	2.70
64		64	0.10	64	0.34	64	0.81	64	1.36	64	2.15	64	3.00
65		65	0.14	65	0.42	65	1.00	65	1.59	65	2.45	65	3.34
66		66	0.18	66	0.52	66	1.21	66	1.85	66	2.78	66	3.72
67		67	0.25	67	0.65	67	1.47	67	2.15	67	3.16	67	4.16
68	0.10	68	0.34	68	0.81	68	1.78	68	2.51	68	3.61	68	4.64
69	0.14	69	0.45	69	1.00	69	2.15	69	2.93	69	4.07	69	5.17
70	0.18	70	0.58	70	1.29	70	2.51	70	3.42	70	4.64	70	5.79
71	0.25	71	0.77	71	1.67	71	2.93	71	3.98	71	5.29	71	6.46
72	0.34	72	1.00	72	2.15	72	3.42	72	4.64	72	5.99	72	7.20
73	0.49	73	1.29	73	2.61	73	3.98	73	5.40	73	6.81	73	8.02
74	0.70	74	1.67	74	3.16	74	4.64	74	6.30	74	7.77	74	9.00
75	1.00	75	2.15	75	3.83	75	5.40	75	7.35	75	8.79	75	10.00
76	1.29	76	2.78	76	4.64	76	6.30	76	8.60	76	10.00	76	11.47
77	1.67	77	3.61	77	5.62	77	7.35	77	10.00	77	11.47	77	12.90
78	2.15	78	4.64	78	6.81	78	8.60	78	11.47	78	12.90	78	14.80
79	2.78	79	5.62	79	8.26	79	10.00	79	12.90	79	14.80	79	16.80
80	3.61	80	6.81	80	10.00	80	11.70	80	14.80	80	16.80	80	19.05
81	4.64	81	8.26	81	11.47	81	13.70	81	16.80	81	19.05	81	21.60
82	5.99	82	10.00	82	12.90	82	16.00	82	19.05	82	21.60	82	23.60
83	7.77	83	11.70	83	14.80	83	18.60	83	21.60	83	24.00	83	25.70
84	10.00	84	13.70	84	16.80	84	21.60	84	24.20	84	26.30	84	28.06
85	12.20	85	16.00	85	19.05	85	24.20	85	27.18	85	29.10	85	30.54
86	14.80	86	18.60	86	21.60	86	27.18	86	30.28	86	31.90	86	33.28
87	17.95	87	21.60	87	24.76	87	30.28	87	33.56	87	35.24	87	36.32
88	21.60	88	25.30	88	28.06	88	33.56	88	37.38	88	38.50	88	39.52
89	25.30	89	29.50	89	31.90	89	37.38	89	41.92	89	42.56	89	42.88
90	29.50	90	34.40	90	36.32	90	41.92	90	47.00	90	47.00	90	47.00
91	34.40	91	40.20	91	41.04	91	47.00	91	51.00	91	51.00	91	51.00
92	40.20	92	47.00	92	47.00	92	51.30	92	55.00	92	55.00	92	55.00
93	47.00	93	51.90	93	51.90	93	55.72	93	59.00	93	59.00	93	59.00
94	52.20	94	56.80	94	56.80	94	60.20	94	64.00	94	64.00	94	64.00
95	58.56	95	62.80	95	62.80	95	65.60	95	68.00	95	68.00	95	68.00
96	65.20	96	68.00	96	68.00	96	72.20	96	74.00	96	74.00	96	74.00
97	72.90	97	75.80	97	75.80	97	78.20	97	80.00	97	80.00	97	80.00
98	80.60	98	83.00	98	83.00	98	84.80	98	86.00	98	86.00	98	86.00
99	90.60	99	91.80	99	91.80	99	92.40	99	93.00	99	93.00	99	93.00
100	100.00	100	100.00	100	100.00	100	100.00	100	100.00	100	100.00	100	100.00

DB	200∼	DB	250∼	DB	315∼	DB	400∼	DB	500∼	DB	630∼	DB	800∼
20		20		20		20		20		20		20	0.10
21		21		21		21		21		21		21	0.11
22		22		22		22		22		22	0.10	22	0.13
23		23		23		23		23		23	0.11	23	0.14
24		24		24		24		24		24	0.13	24	0.16
25		25		25		25		25	0.10	25	0.15	25	0.18
26		26		26		26		26	0.11	26	0.17	26	0.21
27		27		27		27		27	0.13	27	0.20	27	0.24
28		28		28		28	0.10	28	0.15	28	0.23	28	0.27
29		29		29		29	0.12	29	0.17	29	0.26	29	0.30
30		30		30		30	0.14	30	0.20	30	0.30	30	0.34
31		31		31		31	0.16	31	0.23	31	0.34	31	0.38
32		32		32	0.10	32	0.18	32	0.26	32	0.38	32	0.42
33		33		33	0.12	33	0.22	33	0.30	33	0.43	33	0.47
34		34		34	0.14	34	0.25	34	0.34	34	0.49	34	0.52
35		35		35	0.17	35	0.29	35	0.39	35	0.55	35	0.58
36		36	0.10	36	0.20	36	0.34	36	0.45	36	0.62	36	0.65
37		37	0.12	37	0.24	37	0.39	37	0.51	37	0.70	37	0.72
38		38	0.14	38	0.29	38	0.45	38	0.58	38	0.79	38	0.81
39		39	0.17	39	0.34	39	0.51	39	0.67	39	0.89	39	0.90
40	0.10	40	0.20	40	0.39	40	0.58	40	0.77	40	1.00	40	1.00
41	0.12	41	0.24	41	0.45	41	0.67	41	0.88	41	1.08	41	1.08
42	0.15	42	0.29	42	0.51	42	0.77	42	1.00	42	1.17	42	1.17
43	0.18	43	0.34	43	0.58	43	0.88	43	1.09	43	1.26	43	1.26
44	0.23	44	0.40	44	0.67	44	1.00	44	1.18	44	1.36	44	1.36
45	0.28	45	0.47	45	0.77	45	1.10	45	1.29	45	1.47	45	1.47
46	0.34	46	0.54	46	0.88	46	1.21	46	1.40	46	1.59	46	1.59
47	0.40	47	0.63	47	1.00	47	1.34	47	1.54	47	1.71	47	1.71
48	0.47	48	0.73	48	1.11	48	1.47	48	1.67	48	1.85	48	1.85
49	0.54	49	0.86	49	1.25	49	1.62	49	1.82	49	2.00	49	2.00
50	0.63	50	1.00	50	1.39	50	1.78	50	1.98	50	2.15	50	2.15
51	0.73	51	1.11	51	1.55	51	1.97	51	2.15	51	2.33	51	2.33
52	0.86	52	1.25	52	1.72	52	2.15	52	2.34	52	2.51	52	2.51
53	1.00	53	1.39	53	1.94	53	2.34	53	2.55	53	2.72	53	2.72
54	1.14	54	1.55	54	2.15	54	2.55	54	2.78	54	2.93	54	2.93
55	1.29	55	1.72	55	2.34	55	2.78	55	3.02	55	3.16	55	3.16
56	1.47	56	1.94	56	2.55	56	3.02	56	3.31	56	3.42	56	3.42
57	1.67	57	2.15	57	2.78	57	3.31	57	3.61	57	3.69	57	3.69
58	1.89	58	2.38	58	3.02	58	3.61	58	3.92	58	3.98	58	3.98
59	2.15	59	2.61	59	3.31	59	3.92	59	4.26	59	4.30	59	4.30
60	2.40	60	2.88	60	3.61	60	4.26	60	4.64	60	4.64	60	4.64
61	2.70	61	3.16	61	3.92	61	4.64	61	5.00	61	5.00	61	5.00
62	3.00	62	3.50	62	4.26	62	5.00	62	5.40	62	5.40	62	5.40
63	3.34	63	3.83	63	4.64	63	5.40	63	5.83	63	5.83	63	5.83
64	3.72	64	4.23	64	5.13	64	5.83	64	6.30	64	6.30	64	6.30
65	4.16	65	4.64	65	5.62	65	6.30	65	6.81	65	6.81	65	6.81
66	4.64	66	5.17	66	6.21	66	6.81	66	7.35	66	7.35	66	7.35
67	5.17	67	5.79	67	6.81	67	7.35	67	7.95	67	7.95	67	7.95
68	5.79	68	6.46	68	7.54	68	7.95	68	8.60	68	8.60	68	8.60
69	6.46	69	7.20	69	8.26	69	8.60	69	9.30	69	9.30	69	9.30
70	7.20	70	8.02	70	9.11	70	9.30	70	10.00	70	10.00	70	10.00
71	8.02	71	9.00	71	10.00	71	10.00	71	10.90	71	10.90	71	10.90
72	9.00	72	10.00	72	10.95	72	10.95	72	11.70	72	11.70	72	11.70
73	10.00	73	11.10	73	11.90	73	11.90	73	12.60	73	12.60	73	12.60
74	11.10	74	12.20	74	12.90	74	12.90	74	13.70	74	13.70	74	13.70
75	12.20	75	13.50	75	14.10	75	14.10	75	14.80	75	14.80	75	14.80
76	13.50	76	14.80	76	15.60	76	15.60	76	16.00	76	16.00	76	16.00
77	14.80	77	16.35	77	16.80	77	16.80	77	17.20	77	17.20	77	17.20
78	16.35	78	17.95	78	18.40	78	18.40	78	18.60	78	18.60	78	18.60
79	17.95	79	19.80	79	19.90	79	19.90	79	20.00	79	20.00	79	20.00
80	19.80	80	21.60	80	21.60	80	21.60	80	21.60	80	21.60	80	21.60
81	21.60	81	23.40	81	23.40	81	23.40	81	23.40	81	23.40	81	23.40
82	23.60	82	25.30	82	25.30	82	25.30	82	25.30	82	25.30	82	25.30
83	25.70	83	27.40	83	27.40	83	27.40	83	27.40	83	27.40	83	27.40
84	28.06	84	29.50	84	29.50	84	29.50	84	29.50	84	29.50	84	29.50
85	30.54	85	31.90	85	31.90	85	31.90	85	31.90	85	31.90	85	31.90
86	33.28	86	34.40	86	34.40	86	34.40	86	34.40	86	34.40	86	34.40
87	36.32	87	37.10	87	37.10	87	37.10	87	37.10	87	37.10	87	37.10
88	39.52	88	40.20	88	40.20	88	40.20	88	40.20	88	40.20	88	40.20
89	42.88	89	43.20	89	43.20	89	43.20	89	43.20	89	43.20	89	43.20
90	47.00	90	47.00	90	47.00	90	47.00	90	47.00	90	47.00	90	47.00
91	51.00	91	51.00	91	51.00	91	51.00	91	51.00	91	51.00	91	51.00
92	55.00	92	55.00	92	55.00	92	55.00	92	55.00	92	55.00	92	55.00
93	59.00	93	59.00	93	59.00	93	59.00	93	59.00	93	59.00	93	59.00
94	64.00	94	64.00	94	64.00	94	64.00	94	64.00	94	64.00	94	64.00
95	68.00	95	68.00	95	68.00	95	68.00	95	68.00	95	68.00	95	68.00
96	74.00	96	74.00	96	74.00	96	74.00	96	74.00	96	74.00	96	74.00
97	80.00	97	80.00	97	80.00	97	80.00	97	80.00	97	80.00	97	80.00
98	86.00	98	86.00	98	86.00	98	86.00	98	86.00	98	86.00	98	86.00
99	93.00	99	93.00	99	93.00	99	93.00	99	93.00	99	93.00	99	93.00
100	100.00	100	100.00	100	100.00	100	100.00	100	100.00	100	100.00	100	100.00

SOUND PRESSURE LEVEL IN DECIBELS TO LOUDNESS IN SONES

DB	1000~	DB	1250~	DB	1600~	DB	2000~	DB	2500~	DB	3150~	DB	4000~
20	0.10	20	0.10	20	0.11	20	0.14	20	0.17	20	0.20	20	0.18
21	0.11	21	0.11	21	0.12	21	0.16	21	0.20	21	0.22	21	0.21
22	0.13	22	0.13	22	0.14	22	0.17	22	0.22	22	0.24	22	0.24
23	0.14	23	0.14	23	0.16	23	0.20	23	0.24	23	0.27	23	0.27
24	0.16	24	0.16	24	0.17	24	0.22	24	0.27	24	0.30	24	0.30
25	0.18	25	0.18	25	0.20	25	0.24	25	0.30	25	0.34	25	0.34
26	0.21	26	0.21	26	0.22	26	0.27	26	0.34	26	0.37	26	0.37
27	0.24	27	0.24	27	0.24	27	0.30	27	0.37	27	0.41	27	0.41
28	0.27	28	0.27	28	0.27	28	0.34	28	0.41	28	0.46	28	0.46
29	0.30	29	0.30	29	0.30	29	0.37	29	0.45	29	0.50	29	0.50
30	0.34	30	0.34	30	0.34	30	0.41	30	0.49	30	0.55	30	0.55
31	0.38	31	0.38	31	0.38	31	0.46	31	0.54	31	0.62	31	0.62
32	0.42	32	0.42	32	0.42	32	0.50	32	0.58	32	0.68	32	0.68
33	0.47	33	0.47	33	0.47	33	0.55	33	0.64	33	0.75	33	0.75
34	0.52	34	0.52	34	0.52	34	0.62	34	0.70	34	0.83	34	0.83
35	0.58	35	0.58	35	0.58	35	0.68	35	0.77	35	0.91	35	0.91
36	0.65	36	0.65	36	0.65	36	0.75	36	0.84	36	1.00	36	1.00
37	0.72	37	0.72	37	0.72	37	0.83	37	0.92	37	1.07	37	1.07
38	0.81	38	0.81	38	0.81	38	0.91	38	1.00	38	1.15	38	1.15
39	0.90	39	0.90	39	0.90	39	1.00	39	1.07	39	1.23	39	1.23
40	1.00	40	1.00	40	1.00	40	1.07	40	1.15	40	1.32	40	1.32
41	1.08	41	1.08	41	1.08	41	1.15	41	1.23	41	1.41	41	1.41
42	1.17	42	1.17	42	1.17	42	1.23	42	1.32	42	1.53	42	1.53
43	1.26	43	1.26	43	1.26	43	1.32	43	1.41	43	1.63	43	1.63
44	1.36	44	1.36	44	1.36	44	1.41	44	1.53	44	1.75	44	1.75
45	1.47	45	1.47	45	1.47	45	1.53	45	1.63	45	1.87	45	1.87
46	1.59	46	1.59	46	1.59	46	1.63	46	1.75	46	2.01	46	2.01
47	1.71	47	1.71	47	1.71	47	1.75	47	1.87	47	2.15	47	2.15
48	1.85	48	1.85	48	1.85	48	1.87	48	2.01	48	2.33	48	2.33
49	2.00	49	2.00	49	2.00	49	2.01	49	2.15	49	2.51	49	2.51
50	2.15	50	2.15	50	2.15	50	2.15	50	2.33	50	2.72	50	2.72
51	2.33	51	2.33	51	2.33	51	2.33	51	2.51	51	2.93	51	2.93
52	2.51	52	2.51	52	2.51	52	2.51	52	2.72	52	3.16	52	3.16
53	2.72	53	2.72	53	2.72	53	2.72	53	2.93	53	3.42	53	3.42
54	2.93	54	2.93	54	2.93	54	2.93	54	3.16	54	3.69	54	3.69
55	3.16	55	3.16	55	3.16	55	3.16	55	3.42	55	3.98	55	3.98
56	3.42	56	3.42	56	3.42	56	3.42	56	3.69	56	4.30	56	4.30
57	3.69	57	3.69	57	3.69	57	3.69	57	3.98	57	4.64	57	4.64
58	3.98	58	3.98	58	3.98	58	3.98	58	4.30	58	5.00	58	5.00
59	4.30	59	4.30	59	4.30	59	4.30	59	4.64	59	5.40	59	5.40
60	4.64	60	4.64	60	4.64	60	4.64	60	5.05	60	5.83	60	5.83
61	5.00	61	5.00	61	5.00	61	5.05	61	5.50	61	6.30	61	6.30
62	5.40	62	5.40	62	5.40	62	5.50	62	5.99	62	6.81	62	6.81
63	5.83	63	5.83	63	5.83	63	5.99	63	6.50	63	7.35	63	7.35
64	6.30	64	6.30	64	6.30	64	6.50	64	7.14	64	7.95	64	7.95
65	6.81	65	6.81	65	6.81	65	7.14	65	7.77	65	8.60	65	8.60
66	7.35	66	7.35	66	7.35	66	7.70	66	8.48	66	9.30	66	9.30
67	7.95	67	7.95	67	7.95	67	8.48	67	9.21	67	10.00	67	10.00
68	8.60	68	8.60	68	8.60	68	9.21	68	10.00	68	10.95	68	10.95
69	9.30	69	9.30	69	9.30	69	10.00	69	10.90	69	11.90	69	11.90
70	10.00	10	10.00	70	10.00	70	10.90	70	11.70	70	12.90	70	12.90
71	10.90	71	10.90	71	10.90	71	11.70	71	12.60	71	14.10	71	14.10
72	11.70	72	11.70	72	11.70	72	12.60	72	13.70	72	15.60	72	15.60
73	12.60	73	12.60	73	12.60	73	13.70	73	14.80	73	16.80	73	16.80
74	13.70	74	13.70	74	13.70	74	14.80	74	16.00	74	18.40	74	18.40
75	14.80	75	14.80	75	14.80	75	16.00	75	17.20	75	19.90	75	19.90
76	16.00	76	16.00	76	16.00	76	17.20	76	18.60	76	21.60	76	21.60
77	17.20	77	17.20	77	17.20	77	18.60	77	20.00	77	24.00	77	24.00
78	18.60	78	18.60	78	18.60	78	20.00	78	21.60	78	26.30	78	26.30
79	20.00	79	20.00	79	20.00	79	21.60	79	24.00	79	29.10	79	29.10
80	21.60	80	21.60	80	21.60	80	23.60	80	26.30	80	31.90	80	31.90
81	23.40	81	23.40	81	23.60	81	25.70	81	29.10	81	35.24	81	35.24
82	25.30	82	25.30	82	25.70	82	28.06	82	31.90	82	38.50	82	38.50
83	27.40	83	27.40	83	28.06	83	30.54	83	35.24	83	42.56	83	42.56
84	29.50	84	29.50	84	30.54	84	33.28	84	38.50	84	47.00	84	47.00
85	31.90	85	31.90	85	33.28	85	36.32	85	42.56	85	51.90	85	51.90
86	34.40	86	34.40	86	36.32	86	39.52	86	47.00	86	56.80	86	56.80
87	37.10	87	37.10	87	39.52	87	42.88	87	51.30	87	62.80	87	62.80
88	40.20	88	40.20	88	42.88	88	47.00	88	55.72	88	68.00	88	68.00
89	43.20	89	43.20	89	47.00	89	51.30	89	60.20	89	75.80	89	75.80
90	47.00	90	47.00	90	51.00	90	55.72	90	65.60	90	83.00	90	83.00
91	51.00	91	51.00	91	55.00	91	60.20	91	72.20	91	91.80	91	91.80
92	55.00	92	55.00	92	59.00	92	65.60	92	78.20	92	100.00	92	100.00
93	59.00	93	59.00	93	64.00	93	72.20	93	84.80	93	108.20	93	109.00
94	64.00	94	64.00	94	68.00	94	78.20	94	92.40	94	115.40	94	117.00
95	68.00	95	68.00	95	74.00	95	84.80	95	100.00	95	124.00	95	127.00
96	74.00	96	74.00	96	80.00	96	92.40	96	109.00	96	133.00	96	137.00
97	80.00	97	80.00	97	86.00	97	100.00	97	117.00	97	142.00	97	148.00
98	86.00	98	86.00	98	93.00	98	109.00	98	127.00	98	154.00	98	160.00
99	93.00	93	93.00	99	100.00	99	117.00	99	137.00	99	164.80	99	172.00
100	100.00	100	100.00	100	109.80	100	127.00	100	148.00	100	176.20	100	187.00

DB	5000~	DB	6300~	DB	8000~	DB	10,000~	DB	12,500~	DB	16,000~
20	0.12	20		20		20		20		20	
21	0.14	21		21		21		21		21	
22	0.16	22		22		22		22		22	
23	0.17	23	0.10	23		23		23		23	
24	0.20	24	0.11	24		24		23		24	
25	0.22	25	0.12	25		25		25		25	
26	0.24	26	0.13	26		26		26		26	
27	0.27	27	0.15	27		27		27		27	
28	0.30	28	0.16	28		28		28		28	
29	0.34	29	0.18	29	0.10	29		29		29	
30	0.37	30	0.19	30	0.11	30	0.10	30		30	
31	0.41	31	0.21	31	0.12	31	0.11	31	0.10	31	
32	0.46	32	0.23	32	0.14	32	0.12	32	0.11	32	
33	0.50	33	0.26	33	0.16	33	0.14	33	0.12	33	
34	0.55	34	0.28	34	0.17	34	0.16	34	0.14	34	
35	0.62	35	0.31	35	0.20	35	0.17	35	0.16	35	
36	0.68	36	0.34	36	0.22	36	0.20	36	0.17	36	
37	0.75	37	0.37	37	0.24	37	0.22	37	0.20	37	
38	0.83	38	0.41	38	0.27	38	0.24	38	0.22	38	
39	0.91	39	0.46	39	0.30	39	0.27	39	0.24	39	
40	1.00	40	0.50	40	0.34	40	0.30	40	0.27	40	0.10
41	1.08	41	0.55	41	0.38	41	0.34	41	0.30	41	0.11
42	1.17	42	0.62	42	0.42	42	0.38	42	0.34	42	0.13
43	1.26	43	0.68	43	0.47	43	0.42	43	0.37	43	0.14
44	1.36	44	0.75	44	0.52	44	0.47	44	0.41	44	0.16
45	1.47	45	0.83	45	0.58	45	0.52	45	0.46	45	0.18
46	1.59	46	0.91	46	0.65	46	0.58	46	0.50	46	0.21
47	1.71	47	1.00	47	0.72	47	0.65	47	0.55	47	0.24
48	1.85	48	1.07	48	0.81	48	0.72	48	0.62	48	0.27
49	2.00	49	1.15	49	0.90	49	0.81	49	0.68	49	0.30
50	2.15	50	1.23	50	1.00	50	0.90	50	0.75	50	0.34
51	2.31	51	1.32	51	1.07	51	1.00	51	0.83	51	0.38
52	2.47	52	1.41	52	1.15	52	1.07	52	0.91	52	0.42
53	2.65	53	1.53	53	1.23	53	1.15	53	1.00	53	0.47
54	2.84	54	1.63	54	1.32	54	1.23	54	1.06	54	0.52
55	3.04	55	1.75	55	1.41	55	1.32	55	1.14	55	0.58
56	3.28	56	1.87	56	1.53	56	1.41	56	1.21	56	0.65
57	3.52	57	2.01	57	1.63	57	1.53	57	1.29	57	0.72
58	3.77	58	2.15	58	1.75	58	1.63	58	1.38	58	0.81
59	4.04	59	2.31	59	1.87	59	1.75	59	1.47	59	0.90
60	4.33	60	2.47	60	2.01	60	1.87	60	1.56	60	1.00
61	4.64	61	2.65	61	2.15	61	2.01	61	1.67	61	1.07
62	5.05	62	2.84	62	2.33	62	2.15	62	1.78	62	1.16
63	5.50	63	3.04	63	2.51	63	2.33	63	1.89	63	1.23
64	5.99	64	3.28	64	2.72	64	2.51	64	2.03	64	1.32
65	6.50	65	3.52	65	2.93	65	2.72	65	2.15	65	1.41
66	7.14	66	3.77	66	3.16	66	2.93	66	2.38	66	1.53
67	7.77	67	4.04	67	3.42	67	3.16	67	2.61	67	1.63
68	8.48	68	4.33	68	3.68	68	3.42	68	2.88	68	1.75
69	9.21	69	4.64	69	3.98	69	3.69	69	3.16	69	1.87
70	10.00	70	5.05	70	4.30	70	3.98	70	3.50	70	2.01
71	10.95	71	5.50	71	4.64	71	4.30	71	3.83	71	2.15
72	11.90	72	5.99	72	5.05	72	4.64	72	4.23	72	2.38
73	12.90	73	6.50	73	5.50	73	5.05	73	4.64	73	2.61
74	14.10	74	7.14	74	5.99	74	5.50	74	4.97	74	2.88
75	15.60	75	7.77	75	6.50	75	5.99	75	5.34	75	3.16
76	16.80	76	8.48	76	7.14	76	6.50	76	5.70	76	3.50
77	18.40	77	9.21	77	7.77	77	7.14	77	6.12	77	3.83
78	19.90	78	10.00	78	8.48	78	7.77	78	6.55	78	4.23
79	21.60	79	10.95	79	9.21	79	8.48	79	7.05	79	4.64
80	23.60	80	11.90	80	10.00	80	9.21	80	7.60	80	4.94
81	25.70	81	12.90	81	10.95	81	10.00	81	8.14	81	5.20
82	28.06	82	14.10	82	11.90	82	10.90	82	8.72	82	5.54
83	30.54	83	15.60	83	12.90	83	11.70	83	9.35	83	5.89
84	33.28	84	16.80	84	14.10	84	12.60	84	10.00	84	6.21
85	36.32	85	18.40	85	15.60	85	13.70	85	10.95	85	6.60
86	39.52	86	19.90	86	16.80	86	14.80	86	11.90	86	7.04
87	42.88	87	21.60	87	18.40	87	16.00	87	12.90	87	7.48
88	47.00	88	24.00	88	19.90	88	17.20	88	14.10	88	7.90
89	51.90	89	26.30	89	21.60	89	18.60	89	15.60	89	8.40
90	56.80	90	29.10	90	23.60	90	20.00	90	16.80	90	8.93
91	62.80	91	31.90	91	25.70	91	21.60	91	18.40	91	9.40
92	68.00	92	35.24	92	28.06	92	24.00	92	19.90	92	10.00
93	75.80	93	38.50	93	30.54	93	26.30	93	21.60	93	11.10
94	83.00	94	42.56	94	32.28	94	29.10	94	24.20	94	12.20
95	91.80	95	47.00	95	36.32	95	31.90	95	27.18	95	13.50
96	100.00	96	52.20	96	39.52	96	35.24	96	30.28	96	14.80
97	109.80	97	58.56	97	42.88	97	38.50	97	33.56	97	16.35
98	119.00	98	65.20	98	47.00	98	42.56	98	37.38	98	17.95
99	130.00	99	72.90	99	52.20	99	47.00	99	41.92	99	19.80
100	141.00	100	80.60	100	58.56	100	52.20	100	47.00	100	21.60

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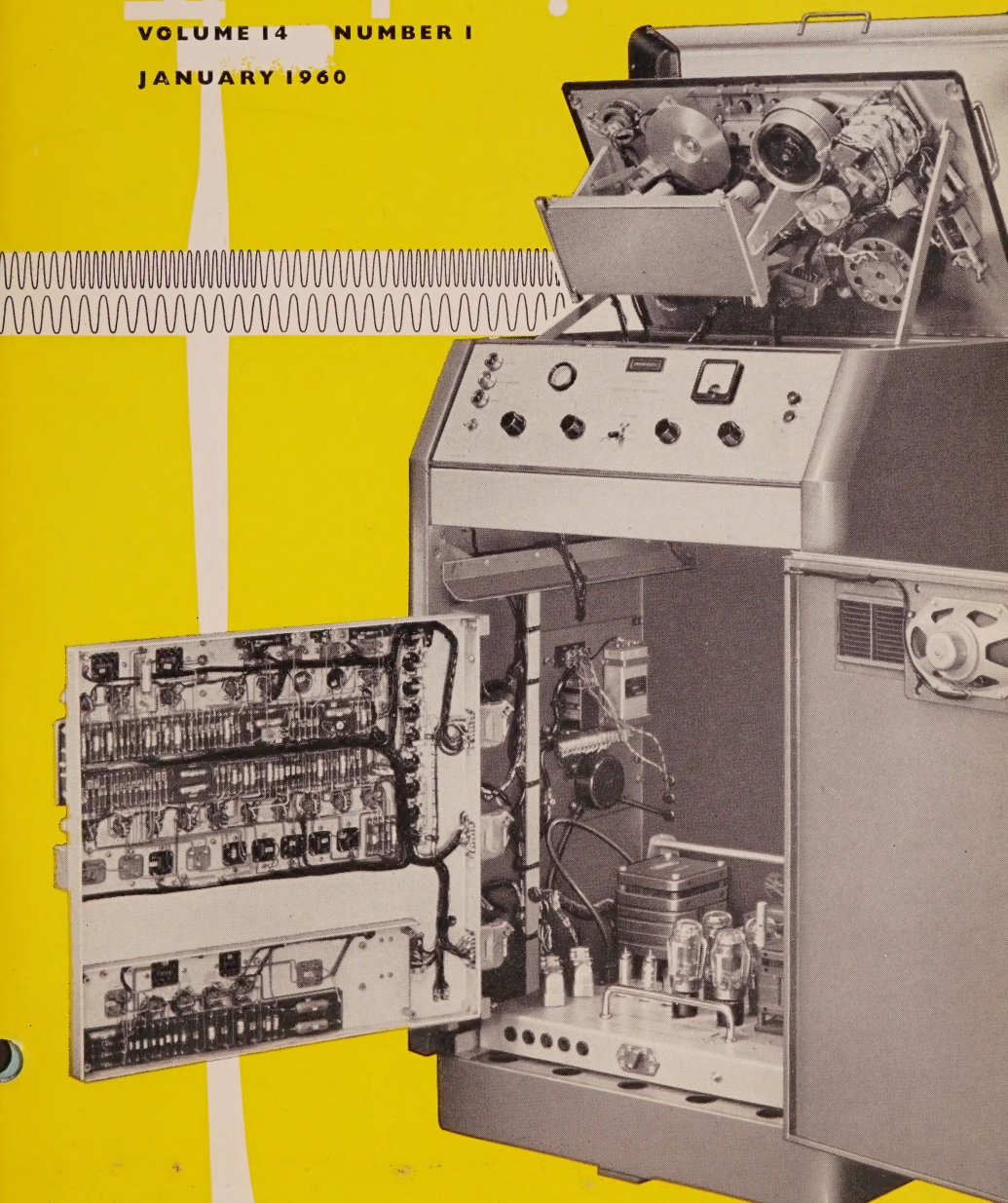

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USE OF RESOLVERS OPERATING AT 10 KC/S AS INPUT DEVICES FOR INDUCTOSYN MACHINE TOOL POSITIONING SYSTEMS Page 3
by E. J. C. Fowell, B.Sc., A.M.I.E.E.

The conventional resolver would make an excellent input device for an Inductosyn position control system were it not for the high carrier frequency commonly used in such systems. Tests carried out on a Muirhead sweep resolver type 23M7A1 indicate that the operation of such an element at 10 kc/s does not significantly increase the rectangularity error when used, either as a feedback device or as a transmitter. A description of an amplifier for use in the feedback connexion at this frequency is included—E.J.C.F.

THE D-880-A 2-PHASE L.F. DECADE OSCILLATOR Page 7
by R. W. Brading, Grad.I.E.E.

The use of integrating amplifiers adapted to function as an oscillator is known and has been described in the literature. The D-880-A 2-phase L.F. Decade Oscillator discussed in Mr. Brading's article embodies many improvements on the basic design calculated to improve frequency stability and output linearity. In accordance with Muirhead tradition, decade frequency selection is provided, the merits of which are now well known and widely appreciated.

THE FRONT COVER

Magnetic tape has invaded many fields for recording a wide variety of signals, e.g. music and speech, mechanical vibrations and the video signals of a television transmission, to name but a few, and bids fair to enter further fields as the technique of tape-recording progresses.

Our cover picture shows the Muirhead D-944 Facsimile Tape Recorder opened up for inspection. This instrument has been developed primarily for use in relay stations handling facsimile transmissions to 'store' picture signals for subsequent retransmission. The illustration clearly shows the unique construction whereby every component in the complex system is readily accessible for inspection and servicing.

ERRATUM

Technique Vol. 13, No. 4
Page 29, Col. 1, line 34—180 should read 108

SIZE 11 MOTOR TACHOMETER

We are pleased to announce that our range of Servomotor-Tachometer Generators has been increased by the addition of a 400 c/s Motor-tachometer in the size 11 frame.

The control phase of the servomotor can be wound for 115V or for lower voltages to suit transistor amplifiers. The tachometer generator has an output of 0·6V per 1000 rev/min. The fundamental component of residual voltage does not exceed 12 mV.

A Data Sheet on this instrument is available on request.

USE OF RESOLVERS OPERATING AT 10 KC/S AS INPUT DEVICES FOR INDUCTOSYN MACHINE TOOL POSITIONING SYSTEMS

by E. J. C. Fowell, B.Sc., A.M.I.E.E.*

The Inductosyn system of linear measurement has found various applications in the point-to-point positioning of co-ordinate tables for boring machines. For such applications the co-ordinate slides of the machines are moved between manufacturing operations, the slides being unclamped and moved, not necessarily in accord, to some new position where the slides are re-clamped prior to a further machining operation. For dynamic positioning, however, under the conditions required for continuous machining, as in a contour milling operation, the input positional information to the machine must represent, at all times, the co-ordinated positions of all the slides, and input information must be presented to the Inductosyn element in a smooth and continuous manner.

The Inductosyn device itself[1,2] utilizes glass scales with an accurately imprinted metallic pattern which is repeated every 0·1 in. Relative movement between such a scale and a close-mounted cursor element, carrying two further interleaved patterns, produces a variation in the inductive coupling between the scale pattern and the cursor patterns, such that when one coupling is at a maximum, the other is at a minimum. Such a device is the linear homologue of the conventional two-pole rotary resolver, and produces nulls, corresponding to rectangle points, in the scale pattern signal for every 1/40th of an inch of relative movement of the scale, upon the sole excitation of alternate patterns on the cursor. Continuous interpolation between these successive rectangle null points is obtained by the partial excitation of both cursor patterns, the positional displacement of the new nulls from the rectangle nulls being determined by the inverse-tangent of the ratio of the magnitude of the two input signals. As there is no iron circuit to enhance the scale-cursor coupling it is necessary to employ a higher excitation frequency in an Inductosyn element-pair, than in a conventional resolver. The recommended operating carrier frequency is 10 kc/s and the input signal required by the cursor element consists of two carrier trains at this frequency whose peak-amplitudes represent the sine and cosine functions of the desired input position measured in terms of the basic unit length of 0·1 in. The representation of polarity of these component signals depends on whether they are in phase or antiphase with respect to the carrier signal.

In the case of a point-to-point positioning system, the input quantities are conveniently produced by means of precision-wound tapped transformers, the taps being set by switch dials or by a punched-card reader. For a continuous control system, such a method becomes extremely cumbersome, and the required data input signals could more easily be obtained from a conventional resolver. Such a resolver, with its rotor excited by the carrier voltage and used in conjunction with an Inductosyn element pair, enables the sought after null point to be moved smoothly along the Inductosyn scale at the rate of 0·1 in. per complete revolution of the resolver shaft.

In the proposed system, for which this investigation was carried out, it is necessary to supply mechanical rotational inputs through two shafts, the difference in rotational angle giving the required output signal to the Inductosyn elements. The required combination of two resolvers is shown diagrammatically in Fig. 1. The left-hand resolver is used as a transmitter unit and the other as a differential device whose output depends on the electrical input angle and the shaft mechanical angle. A feedback connexion is used on the latter unit to maintain accuracy and to prevent one resolver

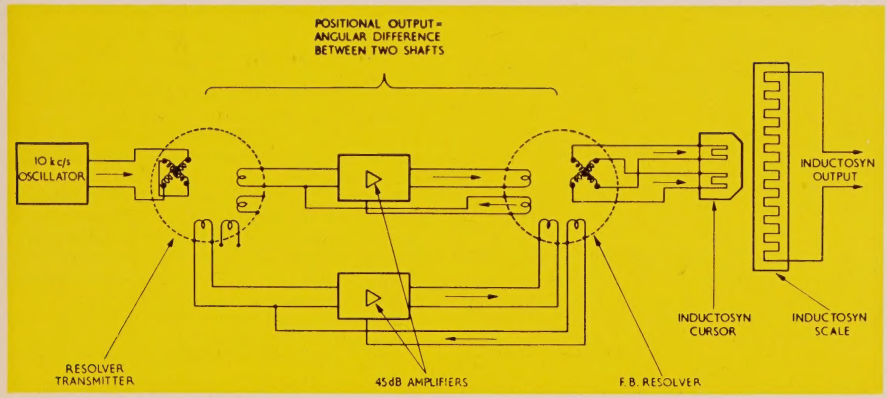

FIG. 1. A suitable input for an Inductosyn control system

* Formerly at the Manchester College of Science and Technology

loading the previous resolver. If the system is to measure displacements of the order of 10^{-4} in. then the resolver system must be accurate to several times better than 1/1000th part of a complete circle, i.e. be appreciably better than 22 minutes of arc. Normal operating frequencies for such resolvers are usually either 60 c/s or 400 c/s and the requirements of high accuracy at an operating frequency of 10 kc/s did not appear to tally with known previous experience. The problem of obtaining a suitable resolver for this application was posed to Muirhead's engineers, who suggested the use of a 23M7A1 radar sweep resolver of the feedback type, with a nominal working frequency of 1 kc/s, although its use with radar sweep waveforms with their numerous harmonics, indicated the possibility of maintained accuracy at higher frequencies.

Tests were carried out on a resolver of this type which was loaned by the makers for the purpose. A 2 volt r.m.s. 10 kc/s carrier signal was used throughout the tests, the resolver being connected in one of two ways, firstly as a feedback receiver arrangement (Fig. 2a), and secondly as a straight connected transmitter unit (Fig. 2b). In each case the output voltages were examined for in-phase component null

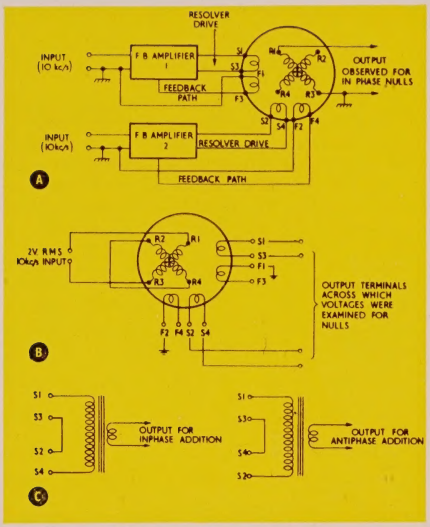

FIG. 2. A—Feedback connexions
B—Straight resolver transmitter connexion
C—Way in which voltages are combined to get '45°+'135°' points, by means of a ferrite ring transformer.

points as the resolver shaft was rotated. The feedback connexion test was carried out with the circuit as shown in Fig. 2a, using feedback amplifiers designed for operation at 10 kc/s (see later section). Signals were fed to either input terminal or simultaneously to both, to give null points at six positions around the circle — four rectangle points, and two antipodal 45° points. Table I shows the median value of deviation from the desired shaft position and also the peak scatter of the individual readings from this value, for the various input signal combinations. Typical values of the quadrature component remaining at the null points are also tabulated, as is the angle between the null points obtained from the alternative rotor windings.

The second series of measurements was carried out with the circuit arrangement of Fig. 2b. One pair of rotor terminals was energized with the 10 kc/s carrier supply and the resolver shaft was rotated to find:

(a) Individual nulls from either of the main stator windings at appropriate rectangle points.

(b) Nulls obtained by adding the voltages from the two main stator windings in either sense in order to detect amplitude equality between the two output voltages.

These occur at 45° from the original datum and at rectangle points therefrom.

Fig. 2c shows the transformer connexions used to obtain this second set of nulls. In this manner nulls were obtained at eight equispaced points around the full circle of shaft rotation. Table 2 shows results obtained both in this simple connexion and also when the unused rotor winding is shorted upon itself. Further results, also in the table, show the efficacy of the unused feedback windings when utilized as rotor-stator screens with one terminal of each winding connected to earth.

TEST CONCLUSIONS

Table 1 shows that for the feedback connexion the extreme deviation in all readings is less than 4 minutes of arc, so that with an appropriately chosen mechanical datum the error can be distributed to be ± 2 minutes of arc. The test figure for rectangularity error given for the resolver at 1 kc/s was ±1·5 minutes of arc so that it would appear that the rectangularity error at 10 kc/s is not appreciably worse than that at the nominal test frequency. The rejection figure for rectangularity error on the 23M7A1 resolver is ±5 minutes of arc, so that it should not be difficult to select units from a production batch with accuracies of 2·5 minutes at 1 kc/s and one may expect to maintain this accuracy at the higher frequency. The quadrature relationship between the two rotor windings is maintained to better than 3 minutes of arc.

The measurements taken on the resolver as a transmitter element (Table 2) show that the maximum deviation could be reduced to 5 minutes of arc, i.e. a rectangularity error of ±2·5 minutes, providing that the following points were observed:

(a) The unused rotor winding was shorted on itself,

(b) That one terminal of each feedback winding was earthed, preferably the one at the 'live' end of the stator winding.

Table 2 also shows that with this form of

earthing the variation in quadrature component size is reduced from 9 :1 to as low as 3 :1. The maximum size of quadrature signal is also reduced from $2\frac{1}{2}$:1 as compared with the earthing of the 'earthy' end of the feedback winding.

These tests indicate the potential accuracy of such a resolver when used in a data transmission system operating at 10 kc/s particularly with reference to an Inductosyn measurement or

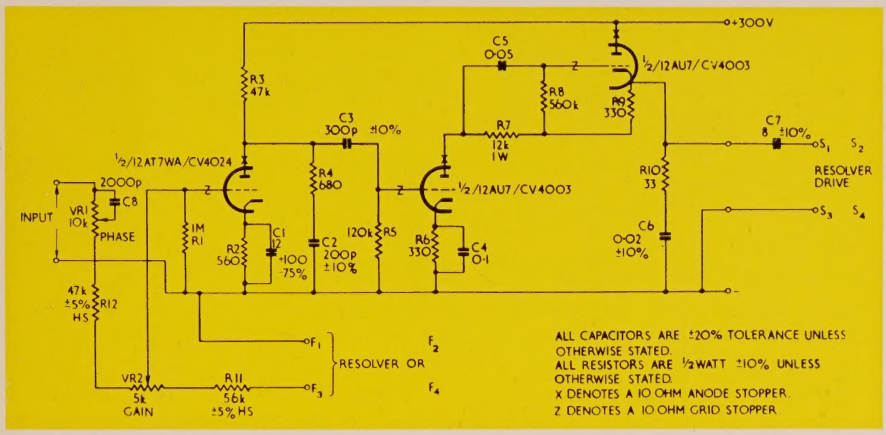

FIG. 3. Feedback amplifier circuit

control system. With the system as shown in Fig. 1 using two resolvers, each with a rectangularity error of 2·5 minutes of arc, it ought to be possible to achieve an overall input system error of less than 11 minutes corresponding to a positional error of 5×10^{-5} in.

DESCRIPTION OF FEEDBACK AMPLIFIER USED

The circuit of the feedback amplifier is shown in Fig. 3. The figure shows a 2-stage amplifier with a total gain of 44dB, allowing for the 3dB attenuation in the feedback path. The inter-stage coupling capacitor C3 is of a small value in order to give a phase lead of approximately 45° at this coupling. The phase shift throughout the amplifier is then approximately zero at the carrier frequency. The tuning capacitor C6 which effectively shunts the resolver winding has its impedance 'built out' by means of resistor R10 for stabilizing purposes. A further transitional lag network, C2 and R4, across the first stage output also assists the stability at the high frequency end of the pass band. The d.c. blocking capacitor C7 has to be made sufficiently large to avoid excessive phase lead in the open circuit characteristic at the low frequency end of the band. The value of C8 was chosen to give adequate adjustment for the setting-up procedure described below.

A complex-plane plot of the amplifier-and-resolver open circuit characteristic is shown in Fig. 4. For the purposes of this plot the signal was fed to the grid of V1 and the output was taken from the slider of VR2. The input terminal was earthed and the slider of VR1 was set to its input-terminal end. As the phase and gain controls used are obviously very inter-dependent, the appropriate setting has to be obtained by alternate adjustment of these controls.

Prior to the tests being carried out, it was necessary to set the phase and gain controls on the two feedback amplifiers. Initially these controls were set up to give near-unity gain and zero phase-shift between the rotor output and the amplifier input terminals, the rotor being positioned to give maximum voltage output and only one stator winding set being energized at a time.

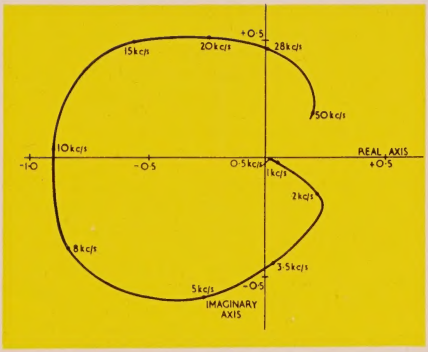

FIG. 4. Open loop gain — 45dB for resolver feedback amplifier

Later, both stator windings were energized together from the same input, and the gain controls were trimmed to give zero in-phase signal at an angle of 45° to one rectangle null point. The quadrature component at this point was now large, but could be reduced by further setting of the phase and gain control,

TABLE 1
23M7A1 Resolver in Feedback Connexion at 10 kc/s (*see Figure 2a*)

S1–S3 Stator Terminals Energized	S2–S4 Stator Terminals Energized	Shaft Angle at which in-phase null expected	Median of Deviation from Desired Angle	Peak § Scatter of Readings from Median	Typical Value of Residual Quadrature Component	Angle Measured between R_1 R_3 and R_2 R_4 nulls	Comments
Yes	No	0°*	Set to zero	—	− 3·5 mV	89° 58′	*Datum angle for each set of readings.
Yes	No	180°	$+\frac{1}{2}'$	$\pm\frac{1}{2}'$	+ 3·5 mV	89° 57′	
No	Yes	90°	− 2′	± 1′	− 2·3 mV	89° 58′	
No	Yes	270°	$-2\frac{1}{2}'$	$\pm\frac{1}{2}'$	+ 2·3 mV	89° 58′	
Yes	Yes	45°	0′†	± 1′	− 4·2 mV	89° 58′	†Amplifier gains adjusted for zero deviation.
Yes	Yes	225°	0′†	± 1′	+ 4·2mV	89° 58′	

The unused rotor terminals were left disconnected in these tests.

+ represents a leading component.
− represents a lagging component.

§ eight readings were taken for each connexion.

TABLE 2
Straight Resolver Connexion (*see Figure 2b*)
(Input to R_1 − R_3 2·0 volts r.m.s. 10 kc/s)

Output from terminals	Desired Angle	R_2, R_4, F_1, F_2, F_3, F_4 not connected		R_2, R_4 shorted F_1, F_2, F_3, F_4 not connected		R_2, R_4 shorted F_3, F_4 earthed		R_2, R_4 shorted F_1, F_2 earthed	
		Deviation from Desired Angle	Quadrature Component at null	Deviation from Desired Angle	Quadrature Component at null	Deviation from Desired Angle	Quadrature Component at null	Deviation from Desired Angle	Quadrature Component at null
S1—S3 alone	0°	0′	0·4 mV	0′	2·4 mV	0′	2·7 mV	0′	0·7 mV
	180°	$-\frac{1}{2}'$	0·4 mV	$+\frac{1}{2}'$	2·3 mV	− 1′	2·5 mV	0′	0·7 mV
S2—S4 alone	90°	− 42′	6·2 mV	− 5′	2·3 mV	− 1′	2·0 mV	+ 5′	0·8 mV
	270°	− 42′	6·2 mV	$-5\frac{1}{2}'$	2·3 mV	− 1′	1·8 mV	+ 5′	0·7 mV
Sum of S1—S3 and S2—S4 outputs	45°					+ 2′	0·4 mV	+ 2′	0·3 mV
	225°					+ 2′	0·3 mV	+ 3′	0·3 mV
Difference of S1—S3 and S1—S4 outputs	135°					− 3′	0·8 mV	+ 3′	0·3 mV
	315°					− 3′	0·7 mV	+ 3′	0·3 mV
Peak Deviation		42′		6′		5′		5′	

even to the extent that in-phase and quadrature components could be nulled together. It was found, however, that this setting did not correspond with the minimum quadrature setting at a 135° point and eventually this quadrature component was made of equal magnitude at the 45° and the 135° points.

For a 2V excitation level at both stator coils, the rotor voltage obtained by the above process was $O + j$ 4·2 mV at the 45° point. As far as possible the adjustment at each stage was taken up evenly between the two amplifiers.

For ease of re-adjustment during servicing, a setting-up jig consisting of the same elements as those involved in the feedback loop (VR1, VR2, R11, R12 and C8) could be made up and connected with its ends in parallel with the ends of the feedback network. The elements of this jig would be preset to the desired values. The amplifier controls could then be set until a null was detected at the output terminal on the jig (corresponding to VR2 slider) by means of a sensitive bridge detector.

This investigation was undertaken as part of an extended programme of research on controlled machine tool topics, being carried out at the Manchester College of Science and Technology under the auspices of the National Research Development Corporation.

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1. H. J. Finden & B. A. Horlock, J.Brit. I.R.E., Vol. 17, No. 7, pp. 369–383.
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THE D-880-A 2-PHASE L.F. DECADE OSCILLATOR

By R. W. BRADING, Grad.I.E.E.*

THE oscillator to be described is based upon a design originated at the Radar Research Establishment, Malvern.[1,2] It provides a new approach to low frequency oscillator design, since it furnishes a means of obtaining a very stable and constant output over a wide frequency range with pure waveform and, when combined with the many improvements which have been incorporated, results in a very useful and versatile instrument.

The most important improvement in its development has been frequency decading, which has enhanced both the frequency accuracy and setting to a very high degree. In order to obtain decading, frequency dependent phase-shift networks have been incorporated to cancel random phase-shifts in the amplifiers and associated components. Each range has its own phase-shift control which is pre-set and only adjusted on frequency alinement of the instrument in order that decading is achieved over the entire oscillator range.

Two outputs have been provided, with a constant phase shift between them of 90°. One of these outputs is capable of feeding into a 600 Ω resistive load over the entire range of the instrument, and is fitted with a precision 62dB continuously variable attenuator as the output control. Particular consideration was given to this output, for which a special two-valve output circuit has been developed that not only reduces the output impedance but also gives sufficient power to enable the 600 ohm load to be connected directly to the oscillator circuit without upsetting or impairing its performance.

Two electronic H.T. stabilizers have been used to improve the frequency stability to an order where precision Muirhead wire-wound resistors and mica condensers could be fully utilized to their ultimate accuracy in determining the frequency of oscillation, at the same time giving additional stability to the output level. Furthermore, very stable components have been used in the circuit where small changes in value could produce deterioration in performance and affect the long term stability.

Constancy of output level, which is an important feature of this oscillator, is better than 2dB (total) over all but the very lowest frequencies (0·03 c/s downwards). However, due to capacitance compensation which has been employed in the main feedback loop, the level constancy is better than 0·75dB over the majority of each range. This means that, by selecting the frequency from the range where maximum decade dial setting accuracy is fully utilized, the output level is in the order of 1dB from at least 1 c/s upwards.

The instrument differs considerably in design from other well known Muirhead decade oscillators, where the basic tuning or frequency selective network is the Wien bridge,[3] by using electronic integrators.

Fundamentally the circuit is a selective amplifier comprising two electronic Miller integrators and a phase inverter of unity gain (worked in cascade) with an overall positive feedback path, to which damping is applied to maintain circuit stability.

It is by the addition of a second or auxiliary feedback path connected between the first integrator output and the phase inverter input, via a limiter, that the selective amplifier becomes self-oscillating, with the amplitude of oscillation being controlled by the limiter circuit. This is perhaps more easily understood by the aid of the basic diagram of the oscillator circuit (Fig. 1) in conjunction with the vector diagram (Fig. 2). It should first be explained however that an electronic Miller integrator has a phase advance of 90°, and at a frequency where the input or series resistance equals the shunt or feedback capacitor reactance, there is an overall gain from input to output of unity.

If we take the voltage at the input E1, to the first integrator as our reference, the output of this integrator, E2, is of similar magnitude to E1 and with a phase advance just a little greater than 90° (the slight increase in phase from 90° being due to the damping condenser C′). The voltage E2 is further advanced by 90° in the second integrator and becomes E3, similar in amplitude to E2. The output E3 is then fed back to the phase inverter by the main feedback loop and thus, after inverting the phase, it is equal to –E3. Similarly, the output of the first integrator is fed back by the auxiliary feedback loop via the limiting circuit, and after, phase inversion, becomes –E′. It will be seen that –E3 and –E′ add vectorially, producing a signal equal in amplitude and of the same phase as E1. Thus the condition for oscillation has been fulfilled, i.e. a 360° phase shift round the loop and an overall gain of unity.

The full expression for the oscillating frequency of the circuit arrangement shown (Fig. 1) is given by $1/2\pi \{ (R4/R3)\ (1/R1\ R2\ C1\ C2) \}^{\frac{1}{2}}$ and in the D-880-A oscillator R4 = R3 = R5 (approx.), R1 = R2 and C1 = C2. The capacitors C1 and C2 are kept constant for a

*Muirhead and Co. Limited

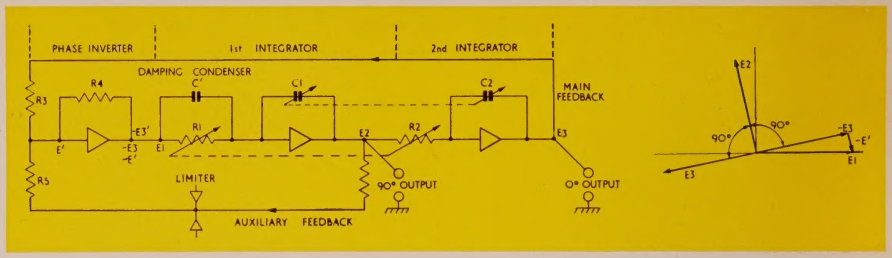

FIG. 1

FIG. 2

given range and R1 and R2, which are ganged decade conductance units, vary the frequency.

It can be seen from the vector diagram Fig. 2 that there is a phase difference of 90° between the outputs of the first and second integrators, viz. E2 and E3, which conveniently enables two outputs in quadrature to be obtained.

APPLICATIONS

Of the many applications to which this oscillator has been put, some have fully utilized its frequency and resetting accuracy and fine frequency control as, for example, in the development and testing of low frequency selective amplifiers and sharp cut-off filters.

Other uses, such as the testing of low frequency amplifier level responses, have necessitated the wide frequency coverage and constancy of output level which the oscillator provides.

One application in particular made use of the two output phases in order to obtain a single output of variable phase (between 0° and 90°) for checking a phase-sensitive instrument. This was achieved by simply connecting a potentiometer between the high potential terminals of the two outputs and taking the new output from the wiper arm and the common low potential terminals. The potentiometer had a scale calibrated from 0° to 90°.

Although only a few uses have been mentioned here the oscillator should find many more, especially in the fields of medical research and servo engineering.

ABRIDGED SPECIFICATION

FREQUENCY RANGE	0·01 c/s – 11·2 kc/s (continuously variable above 0·1 c/s)
V.L.F. Range	0·01 c/s – 0·1 c/s in steps of 0·01 c/s
X0·1 Range	0·1 c/s – 11·2 c/s Smallest Calibrated Division 0·002 c/s
X1 Range	1 c/s – 112 c/s Smallest Calibrated Division 0·02 c/s
X10 Range	10 c/s – 1120 c/s Smallest Calibrated Division 0·2 c/s
X100 Range	100 c/s – 11 200 c/s Smallest Calibrated Division 2·0 c/s
FREQUENCY ACCURACY	From 5 c/s upwards ± 0·2% always obtainable
V.L.F. Range	± 2%
X0·1 Range	± 1%
X1 Range	± 0·2% or ± 0·01 c/s (whichever is the greater)
X10 Range	± 0·2% or ± 0·1 c/s (whichever is the greater)
X100 Range	± 0·2% or ± 1·0 c/s (whichever is the greater)
0° Output	10V R.M.S. into 600 Ω minimum
90° Output	10V R.M.S. into 10K Ω minimum
Phasing accuracy	90° ± 1·5° from 1 c/s upwards, reducing to ± 5° at 0·01 c/s
Equality or proportionality between output levels	0·3dB over entire frequency range
Harmonic content	0° output 0·5% } From at least 0·5 c/s upwards 90° output 1·5% }

References : 1. A Two-phase Low Frequency Oscillator, by E. F. Good, M.A. Electronic Engineering, Part 1, April 1957, Part II, May 1957.

2. British Patent No. 781374.

3. The Decade Oscillator, by E. R. Wigan, B.Sc. (Eng.) and J. A. B. Davidson, M.A. *Technique*, July 1947, Vol. 1, No. 3.

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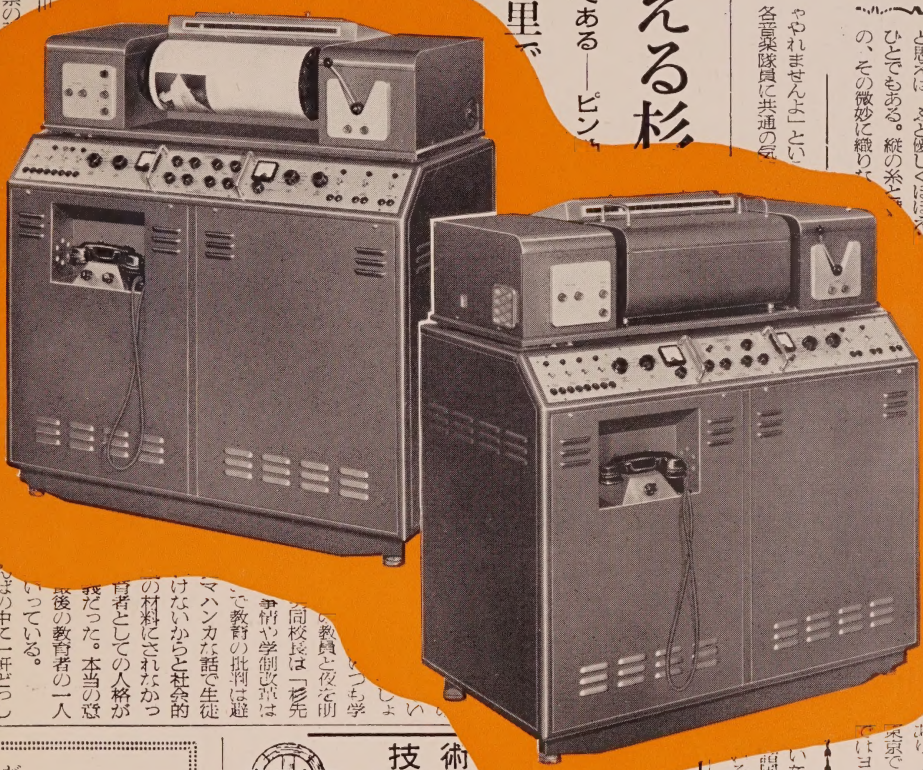
A JOURNAL OF INSTRUMENT ENGINEERING



VOLUME THIRTEEN NUMBER FOUR

OCTOBER 1959

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VOLUME 13 NUMBER 4

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IN THIS ISSUE

MUIRHEAD PAGE FACSIMILE EQUIPMENT page 27
By E. T. A. Phillips

'There's a magic in the distance, where the sea-line meets the sky —'. The 19th century poet, Alfred Noyes, when he penned these lines could have had no conception of the epoch-making event that took place on June 1st 1959, some one hundred years later in the 'Land of the Rising Sun'. For it was on this date that the people of Sapporo in the island of Hokkaido were able to read, for the first time, an exact replica of the *Asahi Shimbun*, one of Japan's leading daily newspapers, at the same time as their compatriots in Tokyo some 900 km. to the south on Honshu island were reading the original publication.

This has all become possible because of the successful marriage between Muirhead facsimile transmitters and receivers, designed to handle full-size newspaper pages, and the latest microwave radio communication systems. We feel certain the foresight and courage shown by the *Asahi Shimbun* in adopting this means of speeding their news service and the one hundred per cent success that has been achieved will encourage other news services to follow suit. In fact, Muirhead once again shows the way to yet another branch of facsimile application.

To mark this event and to give concrete evidence of the complete utility of facsimile page transmission we have produced the article in this issue by E.T.A. Phillips describing the page facsimile process by precisely the same methods. For direct comparison the remainder of this issue was produced normally.

The production of the issue proceeded normally up to the stage when the final page proofs were approved. Then instead of giving the O.K. to the printers to run off the 20 000 copies which constitute a single issue of *Technique*, the pages containing the article were transmitted over a short metallic circuit using a D-854 Facsimile Transmitter and a D-855 Facsimile Receiver. After developing the received film the negatives were sent away for printing plates to be made by an approved photo-etching process and it was from these plates that the article was finally printed on 'newsprint' universally used for newspaper printing.

The fact that the facsimile transmission was virtually back to back is not considered significant since we have ample evidence in the *Asahi Shimbun* that provided the best communication channels are used there is no appreciable loss of definition due to the transmission link.

Relevant Literature

Publication No. 640: Muirhead Newspaper Page Facsimile Equipment — D-854 Transmitters; D-855 Receivers.

MUIRHEAD PAGE FACSIMILE EQUIPMENT

by E. T. A. Phillips*

THE FIRST FACSIMILE NEWSPAPER

From June the first this year any one of the three-quarters of a million inhabitants of Sapporo in Japan's northern island can prop up a copy of a national daily newspaper and read the world's news over his breakfast of rice and salad. To the average person, living in a highly organized community such as the British Isles, this is in no way remarkable, commonplace in fact. But to those people who live in Sapporo, it is a revolution. Previously they have had to make do with the local papers for daily news, for the national dailies have taken two days to reach them by boat and rail from Tokyo. Now, as a result of the latest advance in the art and science of Facsimile, the barriers of distance and weather have been pierced; for three editions every morning and two every evening a microwave radio system carries the *Asahi Shimbun* of Tokyo to the centre of Sapporo. This newspaper, whose name means 'Rising Sun', is using new facsimile equipment recently developed by Muirhead & Co. Limited to project their pages 900 km. northwards into the northern territory. Here the received copy, a film replica of the original page, is processed and used to make the printing plates which set the rotary presses rolling within 75 minutes of the appearance on the streets of Tokyo of the original paper. A new technique has been demonstrated to the newspaper proprietors of the world as practicable and workable, and the financial and cultural benefits could be considerable.

ADVANTAGES OF FACSIMILE REPRODUCTION

Facsimile transmission of photographs for newspapers, of course, has been an established feature for many years and since the last war, development of this equipment, notably by Muirhead, has brought facsimile reproduction to a point where the transmitted copies are almost indistinguishable from the originals. The use of facsimile for transmitting whole pages, including printed matter and pictures, over long distances in such detail that printing plates could be made from the received copies without retouching has hitherto remained rather a dream of the printing engineers. It has long been recognized that such a system, if successful, could have enormous value. It would make possible the reproduction of a newspaper at a distant point which was identical with the original paper, be available on the streets of the distant centre within a short time of publication in the main centre, and most important, could be produced without the need for editing, recomposing and several other expensive and time-consuming printing processes.

Some attempts at this were made by certain London daily papers in the period between the wars but as with many other new enterprises, the successful introduction of a workable and reliable system had to await the technical and administrative development of numerous essential, but not necessarily related, techniques. It must be remembered that two prime necessities for the continuance in business of a newspaper are regular and punctual publication, both of which demand complete reliability in the operation of all stages of a facsimile system, and much credit must therefore be accorded to the *Asahi Shimbun* for their courage in embarking on this enterprise. It is an open secret that this newspaper has expended more than two million pounds on buildings and machinery to implement the facsimile scheme, which materially shows their faith in the facsimile equipment.

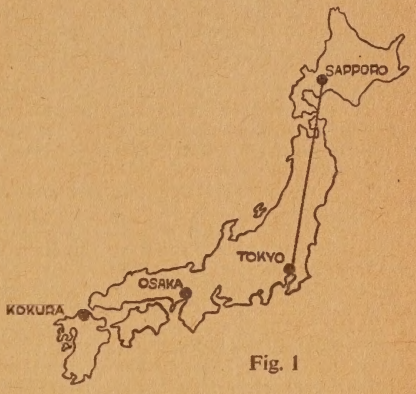


Fig. 1

The outline map of Japan (Fig. 1) shows the locations of the sending and receiving centres.

The principles of operation of the facsimile equipment follow well-established practice and have been described in previous issues of *Technique*.

PROTOTYPE EQUIPMENT

The page facsimile equipment for use in Japan is a further development of equipment originally intended to fulfil the requirements of a British national daily newspaper some years ago. That organization proposed to transmit their newspaper overnight from a provincial city to London, and the approach was made to Muirhead who had already gained a leading position in the field of high quality facsimile communications. Unfortunately, for various reasons the original project was not put into full-scale operation, but the experience gained was invaluable when the Company was approached by the *Asahi Shimbun* for the development of similar equipment.

The machines developed have been designated D-854 for the transmitter and D-855 for

*Senior facsimile engineer: Muirhead & Co. Ltd.

the receiver and are suitable for connexion to either landline or radio circuits of suitable characteristics. The nature of the signal sent from the transmitter to the receiver is an amplitude modulated carrier and this brings in the question of bandwidth, which is one of the fundamentals in the design of this kind of equipment.

One of the basic principles of communication engineering is that information (in a technical sense) is equal to the product of time and bandwidth. A newspaper page contains a comparatively large amount of information (technically as well as otherwise) and consequently requires either a large bandwidth or a long time, for its transmission. Unfortunately, neither bandwidth nor time are freely available; time is extremely valuable in the newspaper business, and bandwidth has to be paid for in money for rental of the circuit, whether that circuit is to be radio or line. Thus a compromise has to be made between the transmission time and a frequency bandwidth which is economical to rent. At the time of writing the compromise has settled, so far as bandwidth is concerned, on the 48 kc/s group which is normally used for carrying twelve telephone channels in a carrier telephone system. This 48 kc/s group may be divided up in many ways to provide sub-channels for the simultaneous transmission of two or more newspaper pages by a battery of facsimile machines.

By far the most difficult problem on the communication circuits available for page facsimile systems is that of delay distortion. This particular form of distortion is caused by a non-linearity of the phase-shift versus frequency characteristic of the circuit and has the effect of delaying the passage along the circuit of certain frequencies. These frequencies are usually those at the edges of the frequency band where the various filters in the circuit start coming into operation. In fact, it can reasonably be stated that delay distortion is a function of the circuit filters and not of the line or the radio path itself. The effect on a facsimile system of delay distortion is to produce a double image at the receiving end, the secondary image being usually of lower intensity than the original, or true, image, but of sufficient density to destroy the definition of very small characters. The higher the speed of transmission and the more fine the scanning definition the greater is the effect of a given delay distortion. Equalization of a circuit to reduce delay distortion is possible, but not always practicable.

While it is quite possible to design phase equalizers to reduce delay distortion on facsimile equipment, it is not an easy matter to produce equalizers which can be adjusted to suit continually changing circuit conditions which arise when a circuit is being rented on a time basis and its constitution may vary from day to day. This problem may not arise to any great extent on radio circuits but can be a considerable headache when line circuits are used which may change from co-axial carrier systems one day to carrier-quad cables the next.

The main purpose of the prototype equipment was to transmit and receive simultaneously four sheets of newspaper of size 24″ × 17″ over a distance of some two hundred miles by carrier telephone circuit. This circuit was to be rented on a time basis overnight. A 48 kc/s group band was selected as forming the best compromise between time and line rental costs, having consideration for the technical factors involved. A battery of four transmitters and four receivers was planned, to give the required facilities. A scanning density of 250 lines per inch was selected as being adequate to deal with the smallest type faces to be encountered, and the speed of scanning was determined at 2·6 lines per second. This gave a transmission time per page of twenty-eight minutes. The video frequency generated by each transmitter was 8 kc/s and transmission was by vestigial sideband amplitude modulation in four sub-channels of 11 kc/s each. This left room for a further channel, some 3 kc/s in width, which was used for sending a synchronizing tone from one transmitter to its three partners and also to the four receivers. The use of vestigial sideband transmission reduced the bandwidth somewhat at the expense of definition, due to delay distortion, but since it was essential to meet the production schedule of eight pages per hour, the loss of definition was judged acceptable.

EQUIPMENT FOR JAPAN

For the *Asahi Shimbun* it was necessary to increase the scanning density to 300 lines per inch in order to define the intricate Japanese characters, many of which include black and white lines of only three-thousandths of an inch in thickness. The standard of printing of Japanese newspapers was found to be extremely good, so good that it was necessary to use originals for transmission which were printed on good quality newsprint paper, rather than art paper on which the ink never seemed to dry.

A scanning rate of 180 rev/min or three lines per second was decided upon and this gave a time of transmission of twenty-seven minutes per page, each page measuring 21⅜″ × 15½″. As with the previous equipment a 48 kc/s group was chosen as the optimum bandwidth and, in order to meet the schedule of four pages per hour, the machines were designed to operate in pairs, transmitting two pages simultaneously. For the sake of maximum definition and freedom from delay distortion, each of the two sub-channels of 22 kc/s was worked double-sideband with a video frequency from each transmitter of 10·5 kc/s. Subsequently, during tests, it was found beneficial to operate these channels somewhat asymmetrically, allowing a video frequency from each transmitter of 12·5 kc/s which gave increased definition without running into the troubles associated with vestigial sideband working.

The actual equipment supplied to Japan is shown in Fig. 2 and the illustrations accom-

panying this article. It will be seen that each transmitter and receiver is of completely self-contained console construction, the mechanism unit being mounted on the top of the console and the electronic equipment mounted on racks within the cabinet. Free access to all parts for servicing has been a feature of the design. The overall dimensions of the consoles are 4′ 2″ high × 3′ 9″ wide × 2′ 1″ deep and the weight of each complete console is 464 lb. The signal output from the transmitters lies within the frequency band 60–108 kc/s, which is the basic group in a carrier telephone system and is the 48 kc/s group which can most easily be assimilated into a public telephone network.

To reduce loss of time through possible electronic failure and for operating and installation convenience, each transmitter and receiver has been made identical with its partner. This means that all machines are capable of operation on either of the two copy-transmission channels and also enables either transmitter to be used as the master in controlling synchronization. An operational advantage gained by this arrangement is that in each console the channel equipment which is not in use is available as spare equipment, which, in fact, may be switched instantly into operation when required. Synchronization is achieved by transmitting a continuous tone from one transmitter to its partner and to the two distant receivers, the tone being generated by a tuning fork of high stability and then used to modulate a carrier within the 60–180 kc/s band, adjacent to but separated from the two facsimile copy channels. This tone also provides a convenient means of controlling the automatic gain control amplifiers on the receiver and the circuit-fail alarm circuits.

As a visible check on the operation of the complete system, 'Mufax' direct recording monitors were designed to work in parallel with the main receivers. These can also be seen in the illustrations. The main purpose of these monitors is to give immediate visible indication of circuit breaks or other faults which may be marring the photographic copy, and which otherwise would not be noticed until transmission is completed, and the film processed.

The outputs at the three channels forming the 48 kc/s band are combined in one of the transmitters and similarly, the inputs to the three receiving channels are combined in one receiver.

In service, the combined transmitter output is fed to a microwave radio transmitter on the roof of the Asahi building in Tokyo and used to frequency-modulate the S.H.F. radio carrier. Subsequently, this emission is combined in the main trunk radio network between the capital and the northern area of Japan.

Photographically, most of the problems in the page facsimile development had already been encountered and solved in previous facsimile developments. The film to be used had to be a compromise between the normal films used for receiving pictures, which lacked sufficient contrast, and the 'lith' type films which could provide extremely high contrast but were too slow in exposure sensitivity to be usable on the facsimile receivers. A very suitable film was available from Ilford Ltd., known as 'Ortholine', which provided this compromise, being sufficiently fast yet capable of producing log densities in the order of 2·5 when used in the receivers. Mechanically also, the problems were expected and were legislated for. A considerable amount of development effort and a high degree of mechanical precision were nevertheless called for, since a very small degree of mechanical imperfection could destroy the legibility of the intricate Japanese characters and possibly produce a disastrous change of meaning.

METHODS OF 'FACSIMILE' PRINTING

Once a facsimile copy has been received there remains, of course, the problem of producing the newspaper from the facsimile copy. Presented with a high quality photographic negative of a newspaper page, there are two practical systems which the printer may use to produce the final newspaper.

The first system, which is most suited to relatively small production, is by 'rotary offset'. In this method, the facsimile negative is printed down photographically on to a lithographic plate which, after simple processing, is fitted to the rotary press and printing commenced. During the printing process, the plate is brushed with water and ink. The water is absorbed by the background area but does not wet the hard and polished exposed characters; the ink, being greasy, remains on the characters, but will not 'take' on the wet background. The inked plate is then rolled in contact with a rubber roller, which receives the ink image of the characters and subsequently transfers it to the newsprint paper. The inking, wetting and transferring process is repeated for each printing and the lithographic plate, which is not too robust, is never in contact with the relatively coarse printing paper. This is the system planned for use initially in Japan.

The alternative method, which is more suitable for large production units, is by 'letterpress printing' and is the best system for feeding a large number of rotary presses simultaneously. In this system, the facsimile negative is photographically printed on to a sensitized zinc plate. This plate is then etched chemically to a depth of 0·012 in. to 0·020 in. and a papier mâché stereotype mat cast from it. The mat is then used to cast the printing half-cylinders of heavy metal which are used on the rotary presses.

Although the letterpress printing method has always been considered the most suitable for printing from facsimile copies, it was not until 1953 that the system became practical. For more than fifty years, the art of blockmaking on zinc plates had remained static and the time taken to etch a plate was upwards of two hours. In 1953, however, the Dow Chemical Corporation

of the United States of America produced an etching machine which was capable of doing the job in ten to twenty minutes. The invention of this, and other so-called 'powderless' etching machines, has made letterpress facsimile printing a workable system. Although originally designed for use with magnesium plates, these machines have been most satisfactorily adapted for use with zinc — a material which is preferred in the printing trade.

FUTURE DEVELOPMENTS

With the introduction of a large-scale scheme such as the facsimile reproduction of newspapers, it is interesting, if not perhaps very profitable, to speculate on future possibilities. Large distances can be bridged, and intercontinental working is already a practical proposition. Whatever the future developments may be, it is reasonably safe to assume that there will be a demand for higher speed; already there exists a requirement for a 'five minute page'. In general, there are three basic communication circuits available which could be used; the 48 kc/s group, the 96 kc/s twenty-four circuit group and the 240 kc/s super group. Increasing the speed of transmission would require a *pro rata* increase in the total bandwidth and similarly increase the circuit rental costs. The pages would arrive faster but still cost the same per page, and the administrative side of the business would have to be streamlined to ensure the continuous flow of pages through the system without waste of time. The basic equation for communication engineers which was mentioned earlier in this article becomes 'Bandwidth × Time = Money' for newspaper systems, and close co-operation between the newspaper organization and the communication authorities would be essential to avoid waste of circuit time.

On the technical side, the difficulty with increasing speed is to maintain quality. Delay distortion effects increase with speed, and there are problems connected with the equipments at higher speeds such as mechanical perfection, light available for exposure and many others. Nevertheless, there is no doubt that all these problems can be solved if the demand for high speed is real.

Full details of the equipment are given in Catalogue Sheet 640 *Muirhead Newspaper Page Facsimile Equipment.*

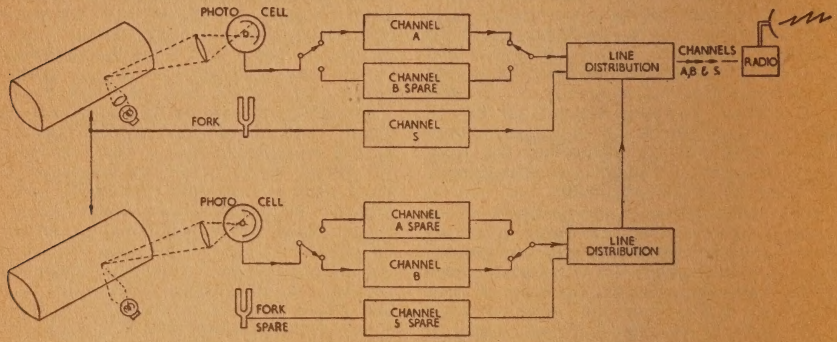


Fig. 2a

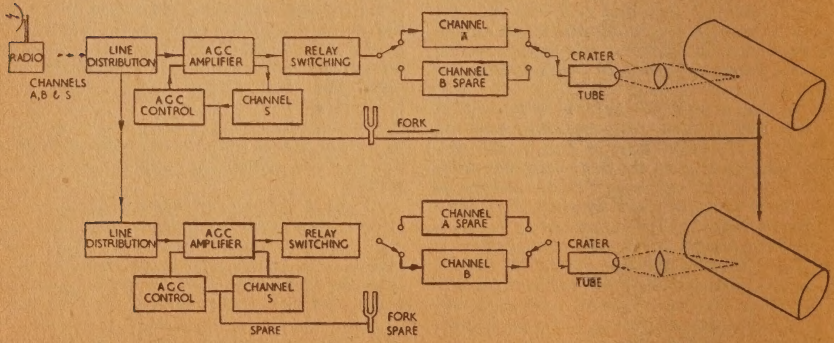


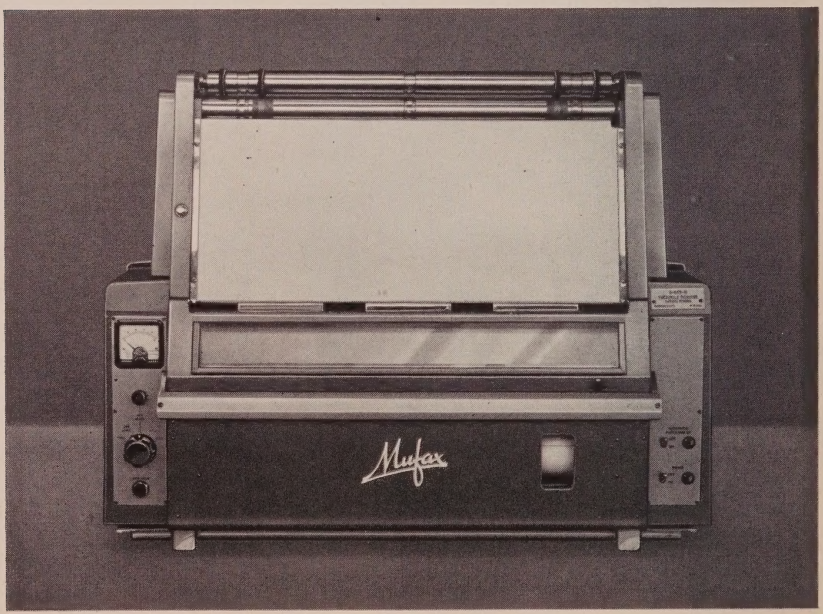
Fig. 2b

Above. Transmitter operator loading the drum with proof copy of page to be sent by facsimile. Each end of the copy is tucked under a clip, and knurled rollers operating under the clips may be turned by the fingers to tighten the copy snugly round the transmitter drum.

Left. Receiver operator communicating by telephone with the transmitter end after the drum box has been loaded with film and fitted into the machine. Speech from transmitter to receiver is carried via the facsimile copy channels and, in the reverse direction as shown here, by separate speech channels on the microwave system.

Above. An historic event. The first film to be received in Sapporo from Tokyo is being examined by our engineer who supervised the installation in Japan. Mr Masao Yoshimura, Engineering Director of the Asahi is in the foreground.

Below. Direct-recording Mufax monitors are used to give visible indication of the progress of a transmission.



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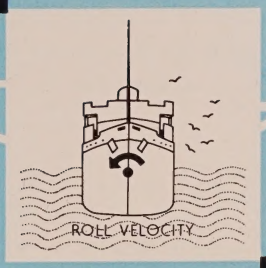

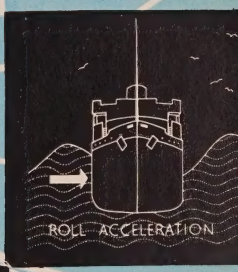

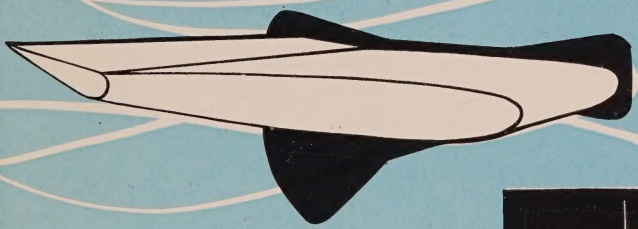

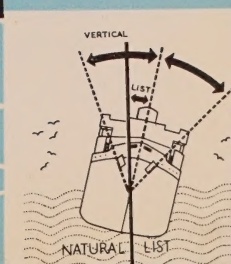

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By J. Bell, M.Sc., M.I.E.E.

THE D-890 MUIRHEAD-WIGAN DECADE OSCILLATOR page 22
By R. F. Griffin, Grad. Brit. I.R.E.

THE FRONT COVER

Almost since its first publication in 1947, reports on Muirhead ship stabilizer control apparatus have appeared in *Technique*, and readers will not have failed to note the steady progress in the development of this equipment that has taken place during the intervening years. From the simple on-off control of 1940, development has lead through successive stages to the present Compensated Control (the subject of an article in this issue) employing no less than five functions of ship and stabilizing motion which are combined to produce continuously the optimum control signal for practically any sea condition to be encountered. These five functions are illustrated diagrammatically — and we hope, artistically — in our front cover design.

That the Compensated Control is the most highly developed of its kind is evidenced by the fact that it will be exclusively used to control all future installations of the well-known Denny-Brown Stabilizer.

SYNCHROS

To satisfy the demands of space limitation a feedback resolver, in a size 11 frame, has been developed and is designated 11RSF4. Used in conjunction with feedback amplifiers this resolver maintains its resolution accuracy with varying input voltages.

A size 11 servometer, for use on 60 cycles, has also been developed and is in production under the designation 11M10A10.

COMPENSATED CONTROL FOR SHIP STABILIZERS

by J. Bell, M.Sc., M.I.E.E.*

INTRODUCTION

SHIP stabilization has been described in *Technique* from time to time, the first article relating to the principles of the Continuous Control.[1]

Improvements in the Control equipment were described in a later article[2] particularly with reference to the introduction of the Hydraulic Relay Unit but no change in the principle of the Control was involved. Thought has been given to the introduction of roll acceleration as a control function in larger vessels but some time necessarily elapsed before the revised ideas could be implemented and practical results in ship stabilization obtained.

This desirable position has now been achieved and an account of the latest equipment together with an indication of its performance appears to be appropriate. The Muirhead Compensated Control equipment senses the motion of the vessel and also by means of a hydraulic amplifier transforms the small signal produced by the sensing apparatus into a mechanical signal of quite significant value giving a mechanical output of the order of 1 in. of travel and 20 to 60 lb. force. This mechanical signal is then used usually through further stages of hydraulic amplification to control the power means actuating the stabilizing device.

Various types of stabilizing device are of course possible; the Denny-Brown system of fins is well known but other systems such as water jets, the movement of a weight on suitable rails across the vessel, or the control of water in tanks, the essential feature being that a torque applied to the vessel is proportional to the signal given from the control equipment. Considerable variations of form may be applied even in the application of the fin system, for example, fins may be of the simple hydrofoil type or they may be the high efficiency type of fin with a flap or with two flaps. Again, instead of a concentrated system in which a pair of large fins are used, multiple fins may be employed having an out-reach comparable with the width of the bilge keel of a vessel and such fins need not therefore be retractable. Whatever the system, however, provided that the law of the torque produced is known, the Muirhead control equipment can be applied to effect the stabilization.

ACCELERATION CONTROL

As already mentioned, some thought was given to the introduction of an acceleration component in the control and the practical working out of this conception resulted in what is known as the 'Compensated Control Equipment'. This will be described in principle and some of the results obtained will be given. In an early conception of the purpose and possible performance of the control it was assumed that the residual motion of the vessel when stabilized would be sinusoidal in character. Experience has shown, however, that this assumption is not true; it implies that roll damping alone is being achieved. The present conception is that ship stabilization should result in holding the vessel substantially vertical on the sea, and that whatever motion remains will be an aperiodical motion having no recognized character.

In an ideal theory, acceleration control alone is needed since the first result of a wave motion on the ship is an acceleration in the direction of the roll. If this were measured instantaneously and the fin angle correction applied in the opposite sense stabilization would be achieved. In practice a certain amount of ship motion is a pre-requisite to sensing the acceleration, and to ensure that this motion is of small amplitude, a high sensitivity accelerometer is needed. The angular acceleration for maximum fin movement in a large vessel is only about 0·30 deg/sec^2, and control action must be initiated at say 5 per cent of this value.

To avoid the use of electronics, the present Compensated Control system uses a differential lever system incorporating a spring and damping unit to derive the acceleration function directly from the movement of a velocity or rate gyroscope. The lever system coupled to the velocity gyro gives a 5 : 1 movement magnification to the acceleration synchro compared with that applied to the velocity synchro. Thus initially for a very small ship-movement the fins are operated by the velocity function and further movement of the vessel, if of a periodic nature, gives true differentiation and the acceleration signal then approximates to a 90-degree phase advance relative to the roll velocity signal.

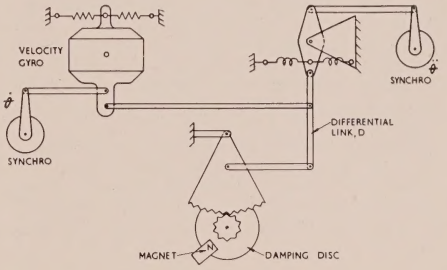

Fig. 1

Fig. 1 illustrates the mechanical arrangement to give the acceleration signal. A velocity sensitive gyro, spring controlled in the normal way, is mechanically coupled to a synchro (or Magslip) generating a signal $\dot{\theta}$. The differential lever attached to the velocity gyro has one end

*Technical Director, Muirhead & Co., Ltd.

secured to a coupling operating a gear sector. This rotates a damping disk running under the poles of a permanent magnet. A pivoted spring loaded lever supports the other end of the differential lever 'D'. This pivoted lever is attached by further linkage to the acceleration synchro $\ddot{\theta}$. If an acceleration is suddenly imposed upon the ship, the gyro deflects instantaneously and the lower end of the lever 'D' can be regarded as a fixture. The upper end being restrained only by the acceleration spring which yields and the acceleration synchro receives the appropriate signal. For conditions of zero acceleration (constant velocity) the velocity gyro takes up its deflected position proportional to the velocity, the acceleration unit also registers a signal, but in a comparatively short time the damping disk spins, releasing the tension of the acceleration springs, so that the acceleration synchro again transmits zero signal.

FIN FEEDBACK

As control from acceleration alone would result in the fins returning to their central position when the acceleration had been neutralized by fin torque, a feedback signal proportional to fin movement is introduced to maintain the fins in the deflected position. The fins then remain still opposing the sea force until the latter changes. This feedback factor is variable and complete balance is attained when it is unity. If it is less than unity the fins will always have a tendency to creep back to their zero position. In practice a feedback factor of 0·7, set up during ship trials, gives the best practical results. The signal operative is written as

$$S=W-F+KF \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where W is the sea couple, F the fin couple acting on the ship. KF is the feedback signal.

NATURAL LIST

A further addition to the control system is the natural list function. This operates from the vertical keeping gyroscope and consists of a servo follow-up unit with a long time constant. The unit follows the roll angle generated, but with a time constant at least 10 times longer than that of the rolling period; the output of the servo therefore settles down to the mean centre of rolling. The vessel is then stabilized about this mean centre. This results in an economy due to the reduction of drag on the vessel as stabilizing power is not used to counter lists due to the normal causes such as wind, and lack of trimming in the ship. If desired the natural list control can be switched out.

THE COMPENSATED CONTROL

Fig. 2 shows diagrammatically the signals and the closed loops involved. The sensing unit provides the roll, roll velocity and roll acceleration signals, the roll signal being modified by a small roll angle inserted by the natural list generator. These three signals and the fin feedback are combined and operate a series of

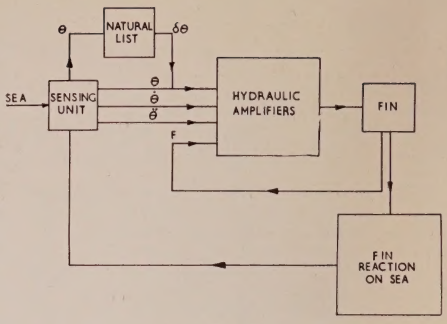

Fig. 2

hydraulic amplifiers. The final amplifier with a power output of up to 100 hp actuates the fin operating rams. A synchro on the fin gives the fin feedback signal while the reaction of the fin on the sea alters the rolling angle of the vessel. This in turn feeds back into the sensing unit, closing the loop.

Control of the stabilizer is seen to be vested in five functions namely roll, roll velocity, roll acceleration, fin feedback, and natural list.

The whole control signal may be written in the simplified form

$$S=K_1\theta+K_2\dot{\theta}+K_3\ddot{\theta}+K_4F \quad \ldots\ldots\ldots (2)$$

K_1 to K_4 are multipliers, constants, time constants, delays and limits appropriate to each function; the roll acceleration $\ddot{\theta}$ in this expression is W − F of equation (1) above, and θ is the roll angle corrected for natural list.

Fig. 3 shows how the signals in Fig. 2 are obtained from differential synchros (Follow-through Magslips) and X-Co Transmitters in addition to the normal transmitters. The synchro M3, operated mechanically by the roll angle gyro, is energized on terminals X Y from the 50 c/s supply and gives out a 3-phase positional control to a differential synchro M4. The rotor of M4 is controlled mechanically according to acceleration, giving direct addition of the angle and angular acceleration, $\theta+\ddot{\theta}$.

In the natural list unit a 2-phase motor is energized on one phase from the main supply. When synchro M3 departs from zero the motor which is sense conscious rotates in one direction or the other. A synchro M1 coupled to the motor through a large reduction gear acts as an induction regulator. When it is driven away from zero, current flows in the cross winding of the X-Co Transmitter M3. The natural list unit runs until zero signal is obtained on the motor. In practice, with the vessel continually rolling asymmetrically on either side of zero, the follow-up unit, because of its long time constant, determines the mean listed position.

A synchro M6 is coupled to the velocity gyro and it, together with the synchro M4, operates synchro M5, controlling the hydraulic relay unit, from which the fins are actuated. The synchro M7 is coupled mechanically to the fin and operates through a potentiometer on the

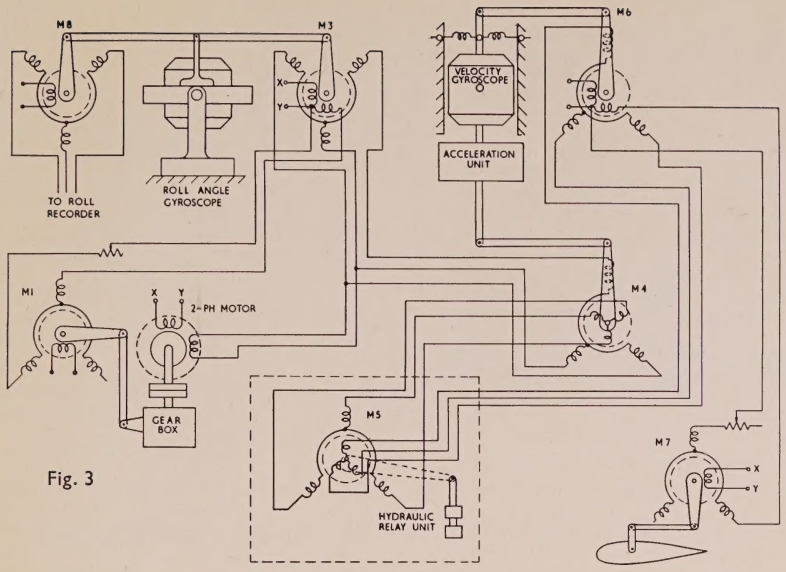

Fig. 3

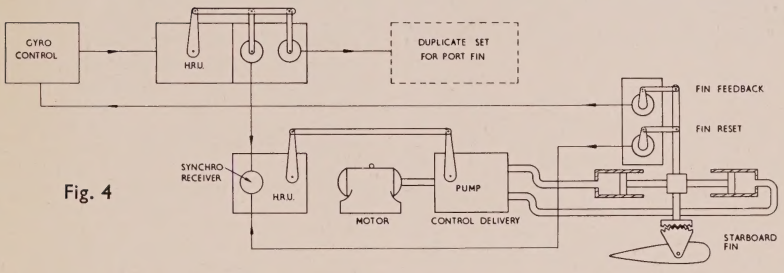

Fig. 4

rotor of M6 similarly to the way the synchro M1 acts on M3. The potentiometer regulates the fin feedback signal and a potentiometer in the output circuit of synchro M1 alters the natural list effect.

Fig. 4 shows diagrammatically the practical layout of one half of one set of the system recently fitted to the 81,000 ton *Queen Mary* (these are identical forward and midship sets). In addition to the controls already described another synchro control is employed in the high-power servo arrangements operating the fins. The output of the first hydraulic relay unit operates a pair of transmitters, each of which controls a further H.R.U., one for the port fin and the other for the starboard fin. These H.R.U's each control the output of a variable delivery pump which directly operates the fin rams. A transmitter coupled to the fin resets the H.R.U., and consequently sets the pump delivery to zero when the fin has executed the movement required. The fin feedback transmitter feeding the gyro unit is mechanically attached to the starboard fin as shown.

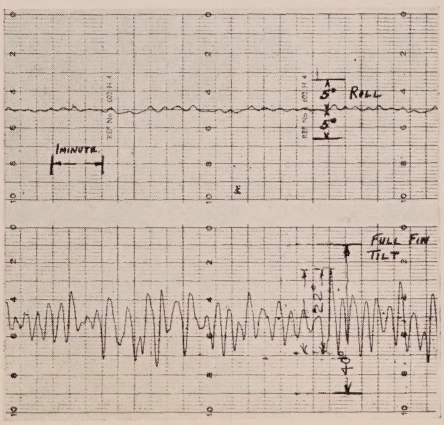

Fig. 5

PERFORMANCE

Fig. 5 shows a record obtained during the vessel's first Atlantic crossing after fitting of the stabilizers. This record shows both ship movement and fin movement. The full fin power was not employed at any time although weather conditions were quite rough and it is estimated that the vessel would have rolled up to 20 degrees out to out. From the roll record it can be seen that this has been kept well within 2 degrees — indiscernible by the passengers.

An interesting record is shown in Fig. 6 of another large vessel. Fin movement and ship roll are both recorded, and it can be seen that when the stabilizer was switched off for only about 25 seconds a roll of over 10 degrees resulted where previously the overall roll was about 3 degrees. A larger roll would have occurred if the stabilizer had not been switched on again.

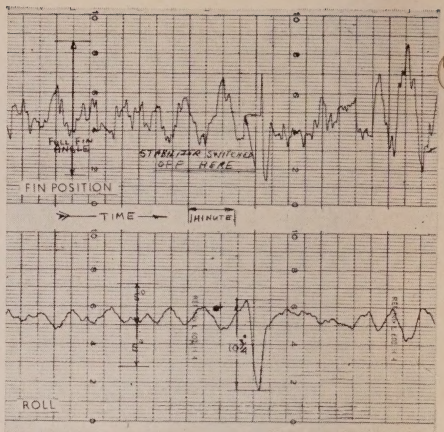

Fig. 6

References :

[1] Technique, Vol. III, No. 2 — Ship Stabilization by J. Bell, M.Sc., M.I.E.E

[2] Technique, Vol. IX, No. 1 — Recent Developments in Ship Stabilization by J. Bell, M.Sc., M.I.E.E.

THE D-890 MUIRHEAD-WIGAN DECADE OSCILLATOR

by R. F. Griffin, Grad. Brit. I.R.E.*

A WIDE range decade oscillator has occupied a prominent position in the Muirhead range of precision instruments for the last 20 years or so.

One of the recent additions to this range is the D-890-A Muirhead-Wigan Decade Oscillator which is the successor to the well known D-650-B oscillator and covers the same frequency range of 1 c/s–111 kc/s. It has many new features and operational advantages, combined with a weight reduction of some 25%. Whilst the principle of operation has not changed from that described in earlier editions of *Technique*,[1 2] automatic control of the oscillator drive level has been developed to the extent that manual control (a feature of earlier types) is no longer necessary. This in turn has led to a reduction in the warming up time and a considerable improvement in frequency and amplitude stability.

It was this improved stability and ease of operation that led to the inclusion of a crystal check facility which increases the frequency accuracy by a factor of 4 to 1 compared with the D-650 instrument, and will be welcomed by users who require frequency accuracies not normally associated with variable frequency oscillators.

IMPROVEMENTS IN DESIGN

The decade switches, of Muirhead design and manufacture, are of the silver graphite self-lubricating type and require no maintenance.

Electrolytic capacitors of the twist prong type have been used where possible to speed servicing, and much attention has been paid to the accessibility of components most likely to require replacement during the life of the instrument. A Post Office type jack and Muirhead terminals have been provided for the output; the terminal heads accept plugs and are mounted on centres suitable for American type 2 pin connectors.

OSCILLATOR CIRCUIT

The circuit is a further development of that used in the Muirhead D-695 oscillator which is widely known for its stability and low distortion. Automatic control of the oscillator drive level is effected by a lamp and a thermistor. This control is remarkable in maintaining the output level constant within ± 1 dB over the range 10 c/s to 111 kc/s and reducing the harmonic content to about $\pm 0{\cdot}2\%$ over most of the frequency range.

A frequency trimmer, giving a constant percentage variation of approx. $\pm 0{\cdot}1\%$ on the X1 range and $\pm 1\%$ on the X10 range, is mounted on the front panel. Continuous variation of frequency below 1000 c/s is achieved by a calibrated control which may be switched in or out and which adds between 1 and 2 c/s to the frequency of oscillation depending on its setting.

Silvered mica capacitors are used in the frequency selective network resulting in enhanced frequency stability with changes in ambient temperature. A typical variation in frequency with change in temperature is $0{\cdot}01\%$ for 20°C rise at 10 kc/s.

The warming up time is 5 min for frequencies up to 10 kc/s increasing to about an hour for frequencies in the 100 kc/s region. The frequency stability is subsequently $\pm 0{\cdot}02\%$ per hour over most of the range.

*Muirhead & Co., Limited

D-890

CRYSTAL CHECK FACILITY

This facility consists of a 2 kc/s crystal oscillator, a one-inch cathode ray tube and independently variable X and Y amplifiers.

The output from the decade oscillator circuit is fed to the Y amplifier while the output from the crystal oscillator is fed to the X amplifier via the EXT. STANDARD jack. Frequency comparison is by means of the resulting Lissajous figure on the cathode ray tube.

The plug-in crystal employed has an XY cut and vibrates in a flexural mode. Following adjustment in the factory the accuracy of the crystal is $\pm 0{\cdot}005\%$ at ambient temperatures of 18° to 40°C. A fine preset control of crystal frequency giving a variation of 150 parts/10^6 is provided but will only require adjustment if certain components in the crystal drive circuit are replaced.

By standardizing the decade oscillator using Lissajous figures it is possible to interpolate to an accuracy of $\pm 0{\cdot}05\%$ for any frequency between 500 c/s and 10 kc/s on the X1 range, and to $\pm 0{\cdot}1\%$ between 10 kc/s and 111 kc/s on the X10 range. For known Lissajous figures e.g. 400, 1000 and 2400 c/s the accuracy of the oscillator can be relied upon to the accuracy of the crystal. If desired, an external standard of any frequency between 10 c/s and 111 kc/s may be applied to the X plates via the EXT. STANDARD jack and the X amplifier.

Any unknown frequency in the range 10 c/s to 111 kc/s may be measured against the decade oscillator by comparison on the cathode ray tube, and by adopting a simple standardizing procedure, utilizing the internal crystal oscillator, unknown frequencies in the range 500 c/s to 111 kc/s can be measured to an accuracy of $\pm 0{\cdot}1\%$ or better.

CHOICE OF CRYSTAL FREQUENCY

The crystal frequency of 2 kc/s was chosen for two reasons. Firstly it enables the decade oscillator to be set to multiples of 1 kc/s over the entire range of the oscillator with an easily recognizable figure. Secondly, it allows this to be accomplished without ambiguity, a point best illustrated by an example. Suppose that a frequency of 100 kc/s is required. With the decade switches set to give this frequency, the frequency trimmer is adjusted to produce a stationary figure, and, since the frequency trimmer varies the frequency by $\pm 1\%$, it is likely that 99 kc/s or 101 kc/s will be obtainable as well as 100 kc/s. With a crystal frequency of 2 kc/s a single line figure will be obtained only when the decade oscillator is set to an even number of kc/s, a double line figure being obtained when set to an odd number of kc/s, so that the possibility of setting to the wrong frequency is eliminated.

OUTPUT CIRCUIT

Two output impedances are available, 600 ohm and 8 k ohm, selection being made with a key switch mounted on the front panel which also selects an appropriate scale on the meter, 0–30 V or 0–150 V. With the output switch set to the 600 ohm position, a maximum of $\frac{1}{2}$ watt is available at 200 c/s increasing to 1 watt at 300 c/s and above, the total harmonic distortion being 1%. With the output switch set to 8 k ohm a maximum of 2 watts is available over the range 20 c/s to 50 kc/s and 1 watt above 50 kc/s, the total harmonic distortion over most of the range being $0{\cdot}6\%$ at 1 watt output, and $1{\cdot}25\%$ at 2 watts. Below 20 c/s the maximum output is 50 mW into 8 k ohm. One side of the 8 k ohm output is at earth potential, while

the 600 ohm output, though not balanced, is normally isolated from earth.

POWER SUPPLY

The instrument is designed to operate from a 50 c/s supply of 95–125 V or 190–250 V. A special version for 60 c/s operation is available.

The H.T. supply for both decade and crystal oscillators is derived from a series-parallel stabilizer, and a constant voltage transformer feeds the heater circuit. It is this latter component that necessitates a special version of the instrument for 60 c/s operation. For ±10% change in mains supply voltage the change in frequency of the decade oscillator varies from ±0·001% at 1 kc/s to a maximum of ±0·02% at 111 kc/s.

The accompanying specification summarizes the features of this accurate and versatile instrument.

SPECIFICATION

FREQUENCY RANGE	
X1 Range	1 – 11 112 c/s
X10 Range	10 – 111 100 c/s
FREQUENCY ACCURACY	
Without Crystal Check Facility	
X1 Range	±0·2% or ±0·6 c/s whichever is greater
X10 Range	±0·4% (above 10 kc/s)
With Crystal Check Facility	
X1 Range	±0·05% 500 c/s–10 kc/s
X10 Range	±0·1 % 10 kc/s–110 kc/s
FREQUENCY ACCURACY OF CRYSTAL	±0·005% (Room temperature 18°–40°C)
HOURLY FREQUENCY STABILITY	±0·02% over most of range, after warming up period 5 mins to 1 hr. (depending on frequency)
MAXIMUM OUTPUT	
8 k ohm load	2 watts. 20 c/s–50 kc/s 1 watt. 20 c/s–110 kc/s 50 mW below 20 c/s
600 ohm load	1 watt. 300 c/s–110 kc/s 0·5 watt at 200 c/s decreasing to 40 mW at 60 c/s
HUM LEVEL	−80 dB ref. 2 watts into 8 k ohm
HARMONIC CONTENT	
1 watt into 8 k ohm	Less than 0·6% down to 60 c/s increasing to 1·5% at 20 c/s.
2 watt into 8 k ohm	Less than 1·25% down to 60 c/s increasing to 2·5% at 20 c/s.
1 watt into 600 ohm	Less than 1% above 300 c/s
CONSTANCY OF AMPLITUDE WITH FREQUENCY	
8 k ohm above 20 c/s	±0·2 dB. 20 c/s–50 kc/s ±1 dB. 20 c/s–110 kc/s
600 ohm above 200 c/s	±0·1 dB 300 c/s–10 kc/s, decreasing to −3 dB at 110 kc/s.
HUM BEAT	Less than 1% peak to peak at mains frequency or multiples.
POWER SUPPLY	
D-890-A	95–125 V and 190–250 V 50 c/s
D-890-A/1	95–125 V and 190–250 V 60 c/s
POWER CONSUMPTION	90 VA
DIMENSIONS	17½ in. (wide) × 10½ in. (high) × 13 in. (deep) (44·5 cm × 26·7 cm × 33 cm)
WEIGHT	64 lb (29 kg)

References:

[1] *Technique*, Vol. I, No. 3 — The Decade Oscillator Parts I & II by E. R. Wigan and J. A. B. Davidson.

[2] *Technique*, Vol. I, No. 4 — The Decade Oscillator Part III by E. R. Wigan and J. A. B. Davidson.

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